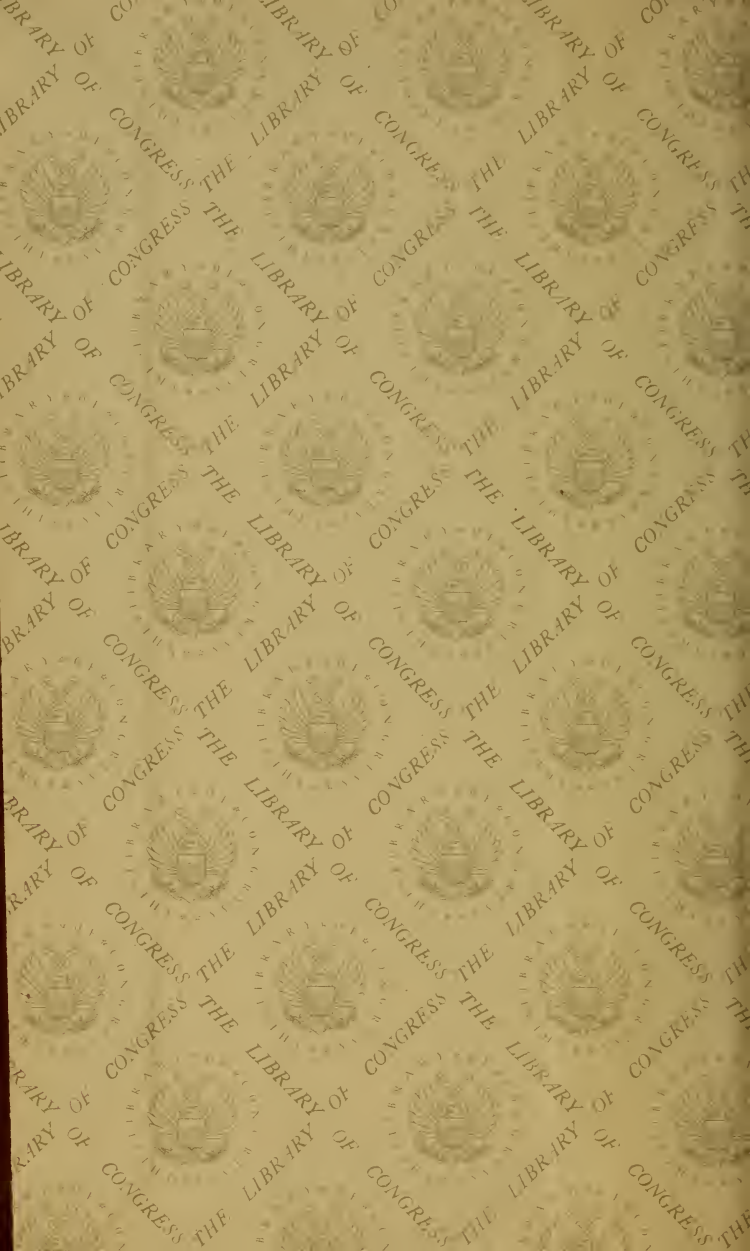
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# ASTRONOMY

FOR

# SCHOOLS.

Saturn and its Rings, as discovered in 1838. See page 147.

# ASTRONOMY

FOR

# SCHOOLS;

UPON THE BASIS OF

MONS. ARAGO'S LECTURES

AT THE ROYAL OBSERVATORY OF PARIS;

AND IN WHICH THE LEADING TRUTHS OF THAT SCIENCE
ARE CLEARLY ILLUSTRATED,

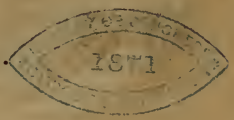
WITHOUT

MATHEMATICAL DEMONSTRATIONS:

WITH NUMEROUS ENGRAVINGS,

AND AN

APPENDIX.



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# PREFACE.

The basis of the following work, as announced in the title page, is Arago's Lectures at the Observatory of Paris. Many changes and digressions from that author have, of course, been necessary, in preparing a work for the schools of the United States, and suited to the wants, and the peculiar paucity of knowledge, upon this particular science, among the greater part of our American youth.

It has often been matter of surprise, and still more frequently of poignant regret, that Astronomy, although the most ancient and the most perfect of all the sciences, should never have been generally introduced into the list of subjects embraced by the first degrees of publick instruction, among us. When the same fact has been complainingly averred in Europe, it has been answered that this science has been, through all former time, exclusively confined to the learned, because the books, upon it, have been so loaded with difficulties as to render access to the science impossible to any others than such as were deeply versed in Mathematicks.

In the lectures of Arago, referred to, above, it was the assumed task of that eminent Astronomer to prepare a work suited to general use, by giving it an elementary form, without sacrificing any thing essential to a general knowledge of the science; and whatever of success may have crowned his efforts, in this, the present work will be found to embrace.

The almost entire absence of the study of this science, from our common schools, and the constant and daily increasing demand for an Astronomy suitable to be used as a Text Book in these schools, are matters of perfect familiarity to all such as have given any considerable attention to the subject of publick instruction, and its progress, in the schools in question.

The rising character of these schools is a proud and distinguishing feature of the present era. The middle aged, of the present day, well remember the first general introduction of the study of geography into our publick schools: now, perhaps, no corner of our land, however obscure, can be found where the schools do not embrace this study, even in laborious detail.

The study of geography has prepared the way for that of Astronomy, of which, indeed, it is, in some sort, a subordinate branch; and which can be well understood only in combination with a knowledge of the mechanism of the heavens.

In the preparation of this work the constant endeavour has been to meet the demand of our common schools, for a Text Book in Astronomy; and to give it general application by suiting it to the capacity of all those who have embraced, in their course of studies, geography, and common arithmetick. For this reason no mathematical problems, whatever, have been inserted; and while it is confidently believed that the work may be fully comprehended by pupils no farther advanced than to embrace the studies above mentioned, it is as confidently hoped that it will be found to include all that is essential to the general pupil in the science.

We have said this science is ancient. It is so: originating in the fields, and among peasants, at a period so early as to be now unknown, it has successively passed from men thus untaught, to minds the most exalted and sublime. Imposing, by the grandeur of its objects; curious, by its peculiar means of investigation; and astonishing by the number and character of its discoveries, it marks, perhaps, more pointedly than any other science, the extent to which human intelligence is capable of fathoming the secrets and the resources of Nature. But, though ancient, in its rude outline, yet perfected astronomy is of very modern date. Though many of the great truths of the science were disclosed by the immortal spirits of previous days, yet it is only about one hundred and twenty years since the true planetary adjustments and motions of the Solar System were taught in the colleges and learned societies of Europe. And yet, such was the rapid march of the science, after that period, that "at the close of the last century there did not remain a single phenomenon, in the celestial motions, that was not explained, on the principle of gravitation."

This minute knowledge, thus perfected only some forty years since, was, of course, confined to the learned; nor is it supposed that others than such will ever attempt to become masters of these abstruse demonstrations. But the spirit of this age, no less than the salutary advantages of the knowledge itself, demands that the results thus discovered, and the general laws by which these results are produced, should become part of the instruction imparted by our schools, to the youth for whose benefit they are maintained. Such knowledge will be a valuable substitute for the lunar, stellary and cometary superstitions, the remnants of that malady of the human mind, ancient astrology, which are so widely diffused, and which can only be ejected from the mind by a substitution of true knowledge in their stead. To this end no study so directly conduces as Astronomy. "The objects which it treats of," says Playfair, "cannot fail to impart to it a degree of their own magnificence and splendour; while their distance, their magnitude, the steadiness and regularity of their movements, deeply impress the imagination, and afford a noble exercise to the understanding. Add to this, that the history of Astronomy is that which is best marked out in the progress of human knowledge. Through the darkness of the early ages, we perceive the truths of this science shining, as it were, by their own light, and scattering some rays around them, that serve to discover a few definite objects, amid the confusion of ancient tradition—a few fixed points amid the uncertainty of Greek, Egyptian, or even Hindoo mythology."

Perfection, of course, I have not hoped to attain; yet great labour has been bestowed, by a constant reference to first authorities, to ensure, as far as practicable, an avoidance of errours which are known to abound in minor compilations.

Every effort, also, has been made, and it is believed successfully, to obtain, from the great Astronomical depositories of Europe, full and accurate knowledge of all the recent discoveries in the science: and the results of these efforts will be found occupying their appropriate places, in the different parts of the work to which they severally pertain.

My hope is that this work may become instrumental in imparting to our youth, in the publick schools, a general knowledge of the leading truths of Astronomy: of that sublime science which

has extended man's views, upon every side; and, by rendering this globe too narrow a space for the range of the human mind, has enlarged its conceptions of the extent, no less than its knowledge of the mechanism of the Universe: of that science which is identified with our daily and hourly necessities; which regulates the labours of agriculture; affords us the only measure of time that we have, or can obtain; is inseparable from accurate geographical knowledge, and is indispensable to navigation: and should it prove useful in this, then, indeed, the end for which it was undertaken will have been fully attained.

THE AUTHOR.

Buffalo, May 10, 1841.

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Pearson, Introduction to Practical Astronomy;
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Jamieson, Celestial Atlas.

## NOTE TO TEACHERS.

The etymological explanation of the several names of the signs of the zodiack has often been attempted; and there is no lack of theories and suggestions, in the books, upon their probable origin and signification. Reference has been made, for this purpose, to the fables of Castor and Pollax, the abduction of Europa, the Argonautick expedition, the passage of Venus and Cupid over the Euphrates—in short, to whatever mythological fable could be found, in the prolifick catalogue of these, that savoured of symbolical representations which might serve as their explanations.

The true meaning of these several names having finally been discovered, through the successful researches of the *Institute of Egypt*, at Paris, these are inserted, at page 59, and onward; but they differ so widely from what has hitherto been taught, upon this subject, that it has been deemed advisable to give them in the several languages through which they have come to us, as well as in English the better to show their authenticity. Another reason for this has been found in the highly figurative language employed, which often admits of only a very loose and general rendering in English, that could scarcely fail, if alone, to prove unsatisfactory to those whose business it is to communicate instruction.

This explanation is made as an apology for the appearance of *Coptick*, *Arabick*, *Greek* and *Latin* words and phrases, in an elementary book; but it is hoped all cause of objection is removed by the fact shown, namely, that these are in no sense intended for the exercises of the pupil, but only for the satisfaction of those to whom he is accustomed to look for elucidation.

# ASTRONOMY.

## CHAPTER FIRST.

### OF ASTRONOMICAL INSTRUMENTS.

Before entering upon the domain of Astronomy, strictly speaking, it is important to know the instruments which opticks has placed at the service of this science, and to the aid of which it owes so much of its perfection: instruments of which the power has augmented the sphere of activity of our organs so as, in some degree, to bring the mechanism of the universe within our view. The study of these instruments will form the object of this chapter.

The construction of *reflecting* telescopes depends upon the laws of the *reflection* of light, and that of *refracting* telescopes upon those of its *refraction.* Let us first examine these two important properties of the luminous fluid.

### GENERAL LAWS OF THE REFLECTION OF LIGHT.

If we cause to fall, obliquely, a pencil of solar rays upon a polished surface, we may observe the following phenomena:

1st. A part of the luminous rays are reflected in a certain direction, and if we place the eye in the line of

this direction, we see an image of the sun, in the prolongation of the reflected rays:

2d. The point where the incident, or approaching rays encounter the polished surface is visible in all directions; but it appears incomparably less luminous, from any other point of view than when observed in the line of the reflected rays—the only view which gives a regular image of the sun:

3d. A portion of the incident light is not reflected, but passes, according to known laws, through the reflecting body, if it is transparent; while if it is opaque the same quantity of light is absorbed.

Here, then, we have three distinct phenomena: one portion of the incident light is reflected regularly, in a particular direction; another part is reflected indifferently, in all directions, and disseminated as if by a body not polished, while the remainder either passes through the reflecting body, or is absorbed by it.

But what is the direction followed by that portion of light which is regularly reflected? We find:

1st. *That the incident and reflected rays are comprised in the same plane, perpendicular to the reflecting surface;* and,

2d. *That the incident and reflected rays always form equal angles with the reflecting surface; or, that the angle of reflection and the angle of incidence are equal.*

Such are the two general laws of reflection; and they very readily explain to us the formation of images, in this way.

Take, first, the plane mirror; suppose, fig. 1, S the radiant point, O the eye of the observer, and A B the plane reflector. Among all the luminous rays emanating from S, there will be one of them, as S I, which, after being reflected, by the mirror, will meet the eye at O, in the direction I O, thus making the angle of incidence equal to the angle of reflection. If, from the radiant point S, we draw the perpendicular

S A, which encounters, at A, the reflecting surface; and if we prolong this perpendicular, upon the opposite side of the mirror, by the quantity A D, equal to S A: then, from the point D, draw the line D O, to the eye; D O will be the direction of the reflected ray, and the point I, where it cuts the surface of the mirror, will be the point of incidence. Moreover, if the luminous object and the eye are both supposed to be mathematical points, without sensible extent, the ray determined by the pre ceding rule, is the only one which can be reflected to the eye.

Fig. 1.

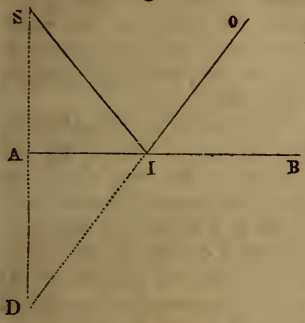
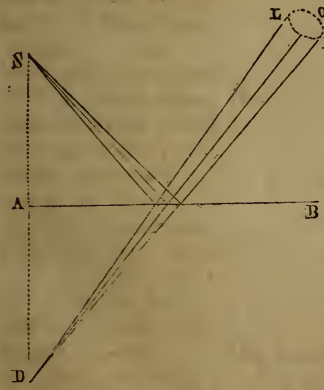



Fig. 2.

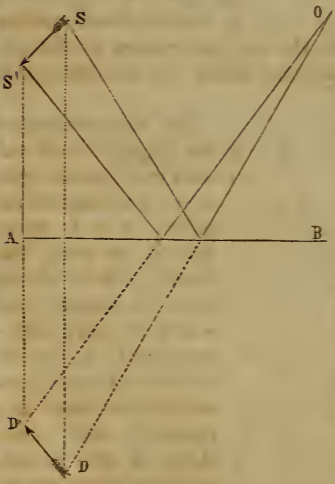



But the opening of the pupil, which admits rays into the eye, is not a mathematical point; it is a space which, in man, has about ,07874 of an inch diameter, and which we may represent by L L, fig. 2. All the reflected rays which can enter this opening, will come, then, to the retina, and thus contribute to vision. Each ray being governed by the same law, which we have here explained, it is

evident that these would form a cone with a circular base, of which the apex would be D, and the base L L. To the eye penetrated by reflected rays the luminous body appears placed at the point from which the visible rays seem to diverge. Thus, the eye being placed at O, the luminous point, seen by reflection, would appear at D; that is to say, the same distance *behind*, that it really is *before* the mirror.

If the radiant object has a defined extent, each of its points of luminous surface will contribute to the formation of its image, according to the rule which we will explain; and the sum of these partial images constitutes that of the entire object. To illustrate this, suppose the object to be an arrow, S S′, fig. 3; the image of the base S, of the arrow, will be shown at D; the point, S′, in like manner at D′; and the intermediate portions of the arrow will be seen, in the right line, D D′. Thus the entire image of the arrow will be comprised between D O, D′ O; its actual size, D D′, will be equal to S S′; in other words, to that of the object itself; but it will appear reversed, from right to left.

Fig. 3.

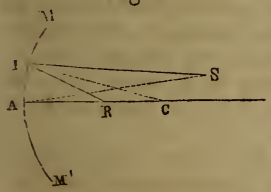



The preceding explanations will suffice for resolving all questions which may arise, relating to the reflection of light and the vision of objects by plane mirrors.

As to curved surfaces, whatever may otherwise be their figure, for determining, in general, the apparent place, the form and the magnitude of the images which they reflect, it will suffice to conceive the reflection of each luminous ray to be made upon the plane tangent to the surface, at the point of incidence. Yet in practical use it is unnecessary to ascend to this general law, since we can never employ any other than spherical, concave or convex mirrors, these being the only ones that we can construct and polish, with accuracy; and even in these, to obtain the most perfect images, it is necessary that the luminous rays fall very near perpendicularly upon their surface. We shall therefore confine ourselves, here, to these figures, alone.

Suppose, then, a luminous point, in space, sends forth its rays upon the different parts of a spherical surface, either concave or convex, and selecting one of these rays, let us seek the direction in which it will be reflected.

Fig. 4.




Suppose M A M′, fig. 4, the spherical mirror, S the luminous point, and S I, the incident ray under consideration. From the point I to the centre of the sphere draw the line I C; then take the angle C I R, equal to C I S, and I R will be the direction of the reflected ray.

By proceeding in like manner with all the incident rays emanating from S, we shall find, either by diagram or by calculation, that the reflected rays all fall very nearly together, within a small space denominated the *focus*, where they form, by their concentration, an image of the point S. Experiment has confirmed the correctness of this theory.

Analogous reasoning and construction show us that the image produced by a convex mirror is always ideal, and is formed *behind* the mirror, so that, although one may view it, by direct vision, it cannot be exhibited upon ground glass, or a screen.

### GENERAL LAWS OF THE REFRACTION OF LIGHT.

We have seen in what manner luminous rays are influenced when reflected from the surface of bodies; and we are now to investigate the action to which those are subject, which traverse the substance of the bodies upon which they fall.

These last, when the angle of incidence is oblique, continue not in a right line, but are made to deviate from that direction; and it is this phenomenon that is called *the refraction of light.*

Whenever a luminous ray passes obliquely from one medium into another, it is refracted; and the extent of this refraction, or deviation from a right line, depends upon the difference which exists between the densities and the natures of the two mediums. In all bodies not crystallized the refracted ray is simple, and follows the prolongation of the plane of incidence. It deviates more or less from a right line to the common surface of the two mediums according as it passes from the more rare to the more dense, or from the more dense to the more rare of them.

It remains to determine the relation which exists, for each incidence, between the obliquity of the incident rays to the perpendicular, and that of the refracted rays, in order to be able to calculate one of its directions, the other being known.

This brings us to the two following laws, discovered by Descartes:

1st. *The incident and refracted rays are always comprised in the same plane, perpendicular to the common surface of the two mediums:*

2d. *The sine of the angle of refraction is to the sine of the angle of incidence in a constant ratio, under all incidences, for the same medium.* This is denominated *the ratio of refraction.*

Refraction is always accompanied by a remarkable phenomenon. The refracted ray is decomposed, and separated into rays of different colours, of which the refrangibility increases from the red ray, where it is the least, to the violet, where it is greatest. This phenomenon is designated, *the dispersion of light.*

In addition to the seven prismatick colours, experiment has shown, in the refracted ray, *calorifick* or heating rays, of which the intensity, according to the prismatick arrangement of the colours, augments from the violet to a point beyond the red; and *chymical* rays, of which the intensity augments in the opposite direction; that is, it is greatest in the red ray, and least at a point beyond the violet.

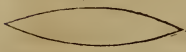
### OF LENSES.

When a luminous ray is received upon a prism of glass it is refracted and caused to approach nearer the base of the prism; conforming also, in other respects, to the laws we are about to explain. Now it is easy to conceive a system, an assemblage of prisms, cut and disposed in such a manner that the rays refracted by them would tend to one and the same point. We realize, at once, how important it would be to be able thus to concentrate a great number of luminous rays; but the difficulty of constructing, with sufficient precision, an apparatus of this kind would have opposed great obstacles to the progress of science, if, by unexpected good fortune, it had not been discovered that the necessary principles were all combined in the spherical lens, which, indeed, is no other than an assemblage of prisms, and which may be constructed with exactness and comparative facility.

Of these we distinguish several kinds:

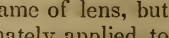
1st. Double convex lens, or glass, fig. 5.

Fig. 5.



The resemblance, in form, of this glass to the seed of the lentil originally gave it the name of lens, but this name has since been indiscriminately applied to all spherical glasses.*

Fig. 6.

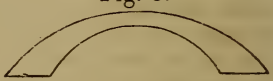


2d. Plano-convex, fig. 6.

3d. Concavo-convex, or meniscus, fig. 7, and fig. 8.

Fig. 7.

Fig. 8.

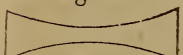


4th. Plano-concave, fig. 9.

5th. Double-concave, fig. 10.

Fig. 9.

Fig. 10.



All these different forms of glasses may be ranked in two classes, according as the base or point of the prism is turned towards the axis of the lens; and as refraction always takes place in a direction towards the base of the prism, the former will cause to *converge*, and the latter to *diverge* the luminous rays which fall in a parallel manner upon their surfaces: hence we sometimes designate one class *convergent*, and the other *divergent* lenses, or glasses.

It is easy to see how such glasses would assist vision, by correcting the too strong or too feeble convergence of rays for the eyes of persons that are defectively long or short sighted; but our object does not require us to dwell upon this point.

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* Lens, *Latin;* Lentille, *French;* Lentil, *English;* a kind of plant bearing a pod in which are contained seeds resembling, in shape, the double convex lens, fig. 5.

Suppose an assemblage of parallel rays to fall upon a convex lens, that we may examine more closely this phenomenon. Among the incident rays, S, fig. 11, there is one which coincides with the axis of the lens, and therefore traverses it without refraction. But with the remaining rays this is not so. They all experience a refraction; and this is greater the farther the point at which they enter the lens is situated from its axis; so that the whole, after passing through the glass, are made to converge to the point F. This point is named the *focus* of the lens. It is evident that the greater the convexity of the lens the stronger will be the refraction, and consequently the nearer will be the focus of the lens to itself. On the other hand, if the luminous rays, after having been assembled at the focus F, are radiated back, to the lens, upon the same angle, they will, after passing through the lens, issue from the opposite surface of it in lines parallel to each other: from which it follows that luminous rays, radiating from any body placed in the focus of such a lens, and so directed as to fall upon all parts of its surface, would experience the same refraction, and issue, after traversing it, in the same parallel manner.

Fig 11.

This property of the lens has given rise to a very useful apparatus, that serves as the base for the construction of the lights of lighthouses; which is no other than an assemblage of four lenses, in the common focus of which is placed a lamp. The luminous divergent rays which escape from the lamp traverse the lenses and issue, in parallel beams, from their opposite surfaces; they consequently are not enfeebled by dispersion; nor do they lose any of their intensity except that portion which is absorbed by the imperfect

transparency of the atmosphere: hence they remain sufficiently brilliant to be clearly visible even at the horizon. But as the diameter of these collections of parallel rays is necessarily circumscribed, their light can only be shed upon a portion of surrounding space, at any one moment. To remedy this inconvenience the whole illuminating apparatus is so adjusted as, by means of clockwork, to revolve, entire, upon a common axis, in a given time. The period of rotation of each being different from every other, and that of each particular one being previously known to navigators, and any one of these times of rotation being easily determined from on board a vessel, by the respective durations of the dark and luminous intervals caused by the rotation of the lantern, such rotation not only enables the mariner to distinguish lighthouse lights from any other on shore, but also to determine what particular one is in view; and thus to instruct him upon what coast he has arrived, and even the particular part of that coast.

Another property of these lenses is that of magnifying the images of objects. Let it be remembered that the apparent dimensions of a body depend upon the angle under which it is seen, and that this angle varies in the inverse ratio of the distance of the object from the eye of the observer. From this it follows that an object would appear of enlarged dimensions by simply placing it near the eye, if the organs of vision were capable of acting, at that point, in perfection; but the divergence of the rays, under these circumstances, renders the image confused. To remedy this we observe the object through a convergent lens. The parallelism of the rays, in this case, admits of the near approach of the eye, and the image of the object appears under an angle equal to that under which the object would appear, to the naked eye, if the organs of vision could act directly upon it, at so small a dis-

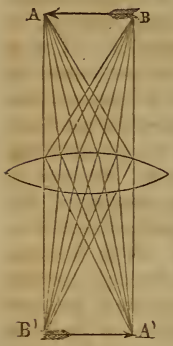
tance. It is evident from this that the magnifying power of the lens is in proportion to its focal length, and that such power is increased as the focal length is diminished.

In the experiment of which we have spoken the idea which we form of the real magnitude of the object is determined by the angle under which it is seen, without our being able to modify it by any previous experience upon the relations of the distance with the visual angles. But in all ordinary acts of vision with the naked eye, this is not so; for in the opinion we there form of the magnitude of objects we always have regard to these two conditions, namely, the angle under which we view the object, and the actual distance at which we suppose that object to be situated. It is in this way that we are enabled to judge as accurately as we do of the stature of two men placed at unequal distances from us, and of course seen under different angles; because the effect of distance, in diminishing objects, is remembered and appreciated. So true is this that we uniformly fall into errour in judging of the real dimensions of objects, if we are much deceived in the distance at which we view them. It is for this reason that objects which we observe through convex spectacles do not seem to us to be magnified, because we suppose them brought nearer, while in fact the glasses magnify some two or three times, perhaps, as we may become convinced by observing the object with both eyes at the same time, while one is aided by the glass and the other is not. We may farther illustrate this by the following simple experiment: place an object upon a horizontal plane, and range the eye in the prolongation of that plane; then, looking at the object, press lightly with the finger, the inferiour eyelid, in such a manner as to produce two images, when that which is nearest will appear smaller than the other, and will seem to diminish in proportion as it

approaches more. A full proof that the supposed distance of the respective images determines our judgement respecting their magnitude is that they will appear to us of equal size when we shall place the object in a vertical plane, in such a manner as to obtain these two images one above the other.

But, to return to the lenses. We have seen by what laws a beam of parallel rays is refracted. We will now examine the manner in which rays emanating from different points of an object are refracted. Suppose A B, fig. 12, an enlightened object. It is evident that from each of the extremities of this object there will depart a pencil of rays, of which the point of convergence will be found somewhere upon the prolongation of the direction of the central ray of that pencil which, having encountered that part of the lens that presented to it *parallel surfaces*, had not been subjected to refraction. The point A, then, in the figure, would be delineated at A′, the point B, at B′, and the intermediate points upon the right line which joins A′ and B′; and if these rays be received upon a sheet of paper, or upon ground glass, a *reversed* image of the object A B will there be exhibited.

Fig. 12.




We have seen, above, that a ray of solar light, refracted, is decomposed in rays of different colours. Such decomposition, therefore, colours the images of objects and renders them confused. This evil is so serious a one that Sir Isaac Newton long sought to remedy it, and finally, despairing of doing so, he proclaimed the attempt a desperate one, and that this must cut off all hope of constructing improved refracting telescopes. Happily the means have since been

discovered of remedying this difficulty. The remedy consists in employing lenses of substances which, while they disperse light equally, refract it unequally. The *crown glass* and *flint glass* of opticians, are such substances; and it is by combining, in proper proportions, lenses of these two species of glass that have been constructed the acromatick object-glasses of telescopes employed in astronomy at the present day.

### OF REFRACTING AND REFLECTING TELESCOPES.

The astronomical refracting telescope, may be considered as essentially composed of two glasses. One, which is named the *object glass*, receives the luminous rays from the object, and of these forms an image of that object, in its focus; the other, which is designated the *eye glass*, is placed near the eye, and assists vision in examining that image. The magnifying power of this species of telescope arises from two causes: the image formed in the focus of the object glass is already magnified, when viewed with the naked eye, because the observer places his eye only some seven or eight inches from it, being a distance much less than that which separates the lens from the focus, and it is consequently seen, thus, under a much greater angle; but the magnifying power of the instrument is principally derived from the eye glass, which is a convex lens whose focal distance is very short. These telescopes are sometimes very powerful: they have been so constructed as to magnify the object, viewed through them, one thousand times.

The cut, fig. 13, will give an idea of this kind of telescope, with one of the numerous methods of mounting it for use. In this figure the tube, *a b*, and the glasses it contains, constitute the telescope. The object glass is at *b*. This is directed towards the celes tial body to be examined, and the rays which fall upon

Fig. 13.

it are refracted to a focus within the tube, near *a*. The image formed at this focus, is viewed through the eye piece *a*, of which each telescope usually has several, of different magnifying powers. The *finder* is a small tube, with glasses, and having two wires crossing each other at right angles, in their focus. When the star is brought, by observation through this finder, exactly upon the crossings of the wires, it is then in the proper position to be viewed through

the main tube. This finder is usually fastened upon the side of the large tube: in this cut it is shown at *d*. By turning the handle *g*, a rotary motion is given to the telescope, upon the upright pillar which supports it; and an apparatus equally simple, but not shown here, gives a vertical motion, at pleasure. With these two motions the instrument is readily pointed in any desired direction.

Instruments of this construction, of large size and high degrees of perfection, have ever been entirely unknown in England; and have been exclusively confined to the continent, both in their fabrication and their use.

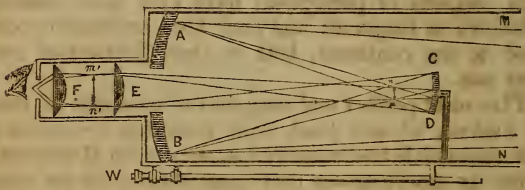
The most perfect and magnificent telescope of this, or, indeed, of any kind, ever constructed—unless a new one which has recently been erected at Rome shall prove its superiour—is that manufactured by the celebrated Fraunhofer, of Munich, for the Imperial Observatory, at Dorpat, in Russia, which is under the direction of Professor *Struve*. It is the property of the Emperour of Russia, and was erected in 1825. Its focal length is 14 feet, and the diameter of its object glass is a fraction less than 9½ inches. Clockwork is so applied to this telescope as to give it a regular and perfect siderial motion, so as to keep a star constantly in the centre of the field of view, thus producing the appearance of a state of entire rest, in the starry sphere; and this motion can be varied at pleasure, to that of the sun, or the moon.

This instrument, in the hands of Professor Struve, has already given vast aid to the science of astronomy; particularly through his examinations of double and multiple stars, nebulæ, &c., the results of which furnish some of the most exciting phenomena that modern research has produced.

The reflecting telescope is constructed of a polished, metallick mirror, in the focus of which the image is

formed, by reflection. Of this instrument there are several forms, differing widely from each other, in many particulars of their construction, and generally distinguished, among astronomers, by the names of the contrivers of the several peculiarities, respectively. Of these we will endeavour to convey a general idea, by drawings and descriptions; commencing with the Gregorian Reflector, fig. 14.

Fig. 14.



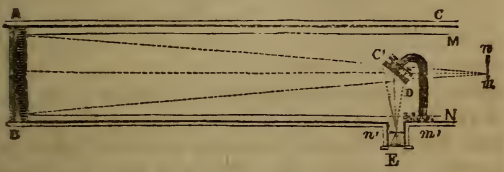

In this figure A B is a concave, metallick mirror, with a hole through its centre. In front of this mirror, is placed a small, concave one, C D, which is moveable by the screw W. An eye piece, consisting of two convex lenses, E, F, is placed immediately behind the great mirror. The incident rays M A, N B, falling upon the great mirror A B, are by it reflected back to the small one C D, and by this last they are again reflected, and passing through the hole in the centre of the great mirror, they reach the eye of the observer, after traversing the two convex lenses, E, F. The rays first reflected by the great mirror, A B, will form an inverted image of the object from which they emanate, at *m n;* and this image, by the subsequent reflection of the mirror C D, will be again formed, but in an erect position, at $m'$ $n'$, between the convex lenses E, F.

The *Cassegrainian Reflector* differs from the Gregorian only in having its small mirror *convex* instead of *concave;* by which the length of the instrument is

much reduced; and it is generally admitted that this form gives more light and exhibits an image better defined, by reason of the correction, by the convex mirror, of the aberration of the concave one.

The *Newtonian* Reflector is represented by figure 15; where A B is a concave mirror, and *m n* the in-

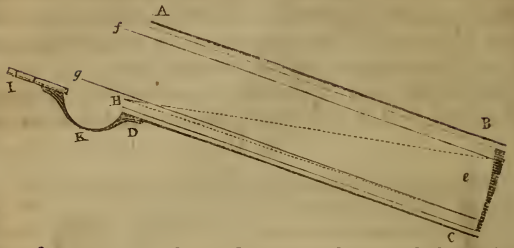
Fig. 15.




verted image which it forms of the object from which the rays M, N proceed. As the eye cannot be introduced into the tube, to view this image without obstructing the light falling upon the mirror from the object to be examined, a plane mirror, C′ D, is placed, upon a proper support, so as to receive the cone of reflected rays, between the great mirror and the image *m n*, and being inclined 45° to the axis of the great mirror, it reflects the image from that mirror to *m′ n′*, where it is magnified by the eye glass E. To avoid the loss of light by a second reflection Newton proposed, in place of the small, plane mirror, C′ D, to substitute a rectangular prism, in which the light would be wholly *refracted;* but as such prisms, sufficiently perfect, both in material and mechanical execution, can rarely if ever be produced, these telescopes are not in use.

But the form of this species of telescope which is now most employed, for astronomical purposes, is the Front View Reflector, figure 16; where A B C D is a tube, at the bottom of which is the reflecting, concave mirror *e*. This mirror is so inclined that the image of the object, from the reflection of the incident

Fig. 16.




rays *f*, *g*, will be formed in the focus of the mirror near H. The image is thus thrown to the side of the tube that the observer may not shut out light from the mirror. In using this telescope the observer, at H, sits *with his back to the object*, and views the image, through an eye glass at the mouth of the tube, whose length varies but little from the focal distance of the reflector, and whose end, A H, must be directed to the object, that the incident rays may enter the tube to fall upon the mirror.

For the convenience of readily giving this instrument its proper direction towards the object to be viewed, a finder, I, of the usual construction, may be attached to the curved arm K, which, rising from the side of the tube near D, is shown to pass round the observer, H, and sustains the finder *behind* him, in a line parallel to the axis of the tube. To use this finder the observer has only to face about, and, with his hand upon the apparatus for moving the tube, regard the object, while he varies the direction of his telescope at pleasure.

As the best polished surfaces do not reflect but about one half of the light which falls upon them, there is a manifest disadvantage, in regard to light, in the use of all the forms of this species of telescope. We may magnify the image, at pleasure, by means of eye

glasses, so long as the light of which it is formed is sufficiently strong to render it distinct: and it is manifest, therefore, that a reflecting telescope, with two mirrors, can have but about *one fourth* the power of a refracting telescope of the same diameter; while those with only a single mirror, all else being equal, have about *one half* the power of such refractor. It is for this reason that the front view reflector is preferred over either of the other forms.

For measuring the heights of the various heavenly bodies, and for a variety of other purposes, telescopes have metallick threads variously adjusted in their fields. These threads exceed, in fineness, the threads of the spider's web, and the process of their manufacture is equally curious and ingenious. They are of platina; and the metal is first reduced, in the ordinary way, to as fine a wire as possible. These wires are then placed in cylinders and melted silver is cast around them, so that the platina constitutes the axis of the cylindrical mass. In this condition they are passed, in succession, through all the wire plates, even to the very finest. Of course, in this process the platina, as well as the silver, is continually reduced in size; and when the operation has been completed, the wire is immersed in nitrick acid, which dissolves the silver, forming the outside of the wire, but leaves the fine thread of platina, in the centre, without acting upon it.

## CONFORMATION OF THE EYE.

We will terminate this chapter with an examination of the organ of vision; the most wonderful of all optical instruments. In man this organ is formed of several different transparent mediums, the curves and the refractive powers of which are so combined as to correct the aberrations of sphericity and refrangibility. The images are formed upon a nervous membrane, at

the bottom or back portion of the eye, which transmits to the brain the sensations it receives.

This organ is composed of three mediums, differing in form and in refractive powers. The first is a meniscus, filled with a transparent liquid, in appearance resembling water, and which, for this reason, has received the name of *aqueous humour*. To this succeeds a solid, transparent body, nearly of the form of a double convex lens, its front surface less curved than its rear one; and having its curvature continually diminished by the approach of old age. This substance is designated the *crystalline humour*. The posterior cavity is supplied with a viscous liquid, resembling melted glass, and which, on this account has been named *vitreous humour*. The envelope which contains all this system, may be considered as formed by the prolongation and extension of the teguments of the optick nerve. The exteriour tegument, constituting the envelope, is hard and opaque, yet flexible, like the cornea, and is called the *sclerotick* coat, or *opaque cornea*. Directly in the front portion of the eye this membrane becomes thinner, and is there transparent, like a lens, that the light may pass through it: this is called the *transparent cornea*. It is exceedingly tough, of equal thickness throughout, and is capable of opposing great resistance to external violence. The *choroid* membrane is a delicate membrane lining the inner surface of the transparent cornea, and is coated, upon the inner side, with a black pigment. This black coating suggested to us the practice of painting black the inside of the tubes of our telescopes: in both cases the black surface absorbs the light that falls upon it, and thus prevents that confusion which would result from the multiplied reflection of scattered rays. The interiour and medullary portion of the optick nerve forms a nervous membrane of a grayish white colour, lying immediately within the black coating of the

choroid membrane, and is known as the *retina*. It is upon the surface of this membrane that the images of objects are *supposed* to be painted.

It is now easy to see how the act of vision is performed. The rays emanating from exteriour objects fall upon the transparent cornea, traverse, successively, the aqueous, crystalline, and vitreous humours, and fall, concentrated, upon the retina, at the focus of the instrument, where they form a small, inverted image. This result may be verified upon the eyes of men or animals, if extracted immediately after death. If the sclerotick coat be reduced in thickness, at its superiour part, and a luminous object be placed at a convenient distance before the eye, the observer may see, from behind, a well formed and clearly defined image of the object, at the bottom of the eye, which will vary in the inverse ratio of the distance. In optical instruments vision is rendered equally perfect at different distances, by varying, proportionately, the focal length of the instrument. By what mechanism is this condition fulfilled, in the eye, where vision is equally distinct at very various distances? That some adjustment of the eye, analogous to the variations of the focal distances in the telescope, takes place, is proved by the fact that a certain time, and even a certain effort of the eye is necessary to adjust its powers to a change in the range of vision. This may readily be demonstrated by placing some small object, a hair, for instance, at a little distance from the eye, in such a manner that its image is projected upon another object, more distant; when it will be found impossible to see both objects, with distinctness, at the same time; but the eye must be made to pass from one to the other, in succession, to obtain perfect views of each. But, though the fact is well established, yet anatomy has essayed in vain to discover by what mechanism this organ is enabled thus to vary its effects. It was at

one time supposed that the anterior part of the cornea assumed, at pleasure, a greater or less degree of convexity; and, again, that the retina was endowed with a small degree of mobility, and that in like manner it receded or approached, so as to follow the displacements of the focus; but the most precise experiments have demonstrated the falsity of these two hypotheses. There remains, then, the crystalline humour, to produce this phenomenon; and we think, notwithstanding that it is impossible for us wholly to reconcile this view with the data furnished by anatomy, that it is to this humour that the eye owes the power in question; for in cases of injury to this humour the eye loses the faculty of distinct vision, at unequal distances. This is the case with persons who have submitted to an operation for cataract, (which operation consists in rupturing this humour, and removing from the line of vision that portion of it which disease has rendered opaque,) for such persons only see well, afterwards, at a given distance, and this an increased one; constituting them what are sometimes designated long sighted persons.

But how does the act of vision give rise to sensation? This we know not: we only know that the impression produced upon the retina is transmitted to the brain by the optick nerve. From this data Mariotte supposed that the nearer the image approaches to the point where the nerve begins to spread or open itself upon the retina, the more vivid the sensation would be, and that it attained its maximum of intensity when it was formed upon the very point of the nerve's termination. But experience yielded him a diametrically opposite result; for he saw, by a very simple experiment, that this part of the retina is insensible, and that an object becomes invisible the moment it is placed in such a manner as to cause its image to fall upon that point.

The axis of the eye, that is the direction in which we habitually regard objects, is not that in which we see objects best. The part of the retina which corresponds to this axis is hardened by use, and is less sensible than the adjacent parts. We consequently see an object much better when regarding it a little upon one side of the axis of the eye. This is the reason why astronomers say that, to view a star well, it is necessary to look a little upon one side of the body, and not directly towards it.

The sensation produced upon the retina, by luminous rays, has a sensible duration. This may be demonstrated by moving a burning coal, rapidly through a circle, in the air, when the entire circle thus described, will appear luminous and glowing. The same may be shown by placing a burning coal upon a wheel revolving rapidly, and so adjusted that it shall pass, at each revolution, before a small hole in a screen, through which it is visible only when directly opposite. In such a case the coal will appear to be constantly present, and at rest, if its revolution is so rapid as to bring it opposite the hole in the screen, twice in every second.

If we look long upon the same colour, we thereby produce a morbid sensation in the fibres of the retina, which renders it less fit, for some time, to perceive that colour, and causes the complementary colours to prevail. It is for this reason that, after having steadily looked upon red or green, we see upon the objects we next observe spots of these colours, for they are complementary of each other; that is, by adding them together, white may be produced.

It has been deemed probable that the fibres which perceive one colour are not the same as those employed in distinguishing another. This, at least, seems to result from one incontestible fact, namely, that there are persons who are unable to perceive and

distinguish all the shades of colours. *Colardeau* was one of these. He sometimes occupied himself in painting; and he one day coloured the background of a picture scarlet instead of sombre. When a friend pointed out to him his errour, he was unable to distinguish any difference in the two colours. There is now living, in England, a celebrated scholar who discovered, while examining certain plants, that he was not conscious of all the colours; and the annals of the Academy mention an entire family who so confounded green with red that they could distinguish the leaves and fruit of the cherry tree only by their respective forms. Cases of this kind may be, and indeed are, continually found, when sought for, in almost every considerable neighbourhood; and Phrenology has shown us that this fact, hitherto inexplicable, is inseparably connected with defective developement of a certain portion of the brain.

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## CHAPTER SECOND.

### HISTORY OF ASTRONOMY—DEFINITIONS.

A thick cloud obscures the cradle of all the sciences; but that one of which the history is enveloped in the most profound obscurity, perhaps, of them all, is Astronomy. Equally ancient as the world, and intimately related to the first necessities of man, from his earliest existence, it cannot have failed to excite his curiosity and attract his observation. But these first elements of astronomy, collected in various places, greatly elongated from each other, were then lost to the science, as they now are to its history.

We propose not, therefore, to detail the history of this science, from its infancy to the present moment,

without for one instant losing sight of it, amidst the darkness by which it is surrounded, but only to catch a glimpse at it, here and there, through the cloud by which it is covered.

The Chaldeans were perhaps among the first who occupied themselves with astronomy. This pastoral people inhabited the delicious regions of Asia, the finest country of the earth. Their habits of passing their nights in the open air, the serenity of their sky, the great extent of their horizon, must all have combined, very early, to induce these people to follow the movements of the heavenly bodies, and to study their imposing phenomena.

From Chaldea astronomy rapidly spread itself into Egypt, that cradle of the arts and sciences, where it soon made great progress. The priests seizing upon it, engrafted it upon their system of religion, and made of it an instrument of domination over a credulous people, whom it was their study to retain in ignorance and superstition.

The Phenecians appear to be the first who applied astronomical observations to the purposes of navigation. They had observed that amidst the general movement of the sphere, one of the stars of the constellation Little Bear appeared ever to remain in the same situation. It was by this star that they guided their vessels; and such was their superiority that, in the time of Necho, at an epoch, when the other nations scarcely dared to quit the coast, they, having departed from the Red Sea, had made the tour of Africa, and returned, the third year, to the mouth of the Nile.

About the same epoch astronomy was carried from Phenecia, by Thales, into Greece. He instructed the Greeks, who had hitherto regarded only Ursa Major, in the superiority of the pole star, as a guide for navigation. He taught them the laws of motion of the

sun, and of those of the moon; from which he drew the explanation of the lengths of days and the determination of the solar year. He knew the causes of eclipses; and, it would seem, even the means by which to foretell them, since he acquired a great degree of celebrity for having announced one which took place on the day of a battle between the Medes and the Lydians.

Anaximander, one of his disciples, invented the terrestial globe, and caused to be constructed, at Sparta, the gnomon, which served him to observe the equinoxes and the solstices, and to determine, with much precision, the obliquity of the ecliptick. The Greeks soon applied these new ideas to profit, in the purposes of navigation; but they were not grateful to him whose wisdom had taught them these truths. They proscribed him, and would even have put him to death if Pericles had not checked the fury of the superstitious people. His crime consisted in having professed that the universe is governed by immutable laws.

Pythagoras, who lived about five centuries before our era, greatly conduced to the advancement of this science. He enriched it with almost all the great outlines upon which it now reposes. It was he who discovered that system of the world to which Copernicus has left his name. It was he who first entertained the daring conception that the planets are inhabited globes, like that upon which we tread; and that the stars which people the immensity of space are so many suns, destined to dispense heat and light to the planatary systems which gravitate towards them. He saw, also, in comets, not transient and fugitive meteors, formed in our atmosphere, but permanent heavenly bodies, revolving round the sun, in conformity with laws peculiar to themselves.

The first who learned to class the climates according to the length of days and nights, was Pytheas, who

witnessed, if he did not cause the rise, among the Greeks, of a decisive taste for astronomy. Unable to satisfy themselves at Athens, these astronomers ascended to the sources of this science: they went to study in Egypt; and Eudoxus brought back with him on his return, much new information which he imbodied in several works. It was he who explained to the Greeks, and caused them to adopt, the famous cycle of nineteen years, imagined by Meton, to reconcile the movements of the sun and the moon. The year of this cycle is still indicated, in our calendars, under the name of *Golden Number*.

The sciences are all allied, and they mutually aid each other. Astronomy has lent its assistance to both Philosophy and Geography. Aristotle determined, by astronomical observations, the figure and magnitude of the earth. The proof of its sphericity he deduced from the appearance of the shadow which it projects, circularly, in eclipses, upon the disk of the moon; and from the inequality of meridian solar heights, in different latitudes.

Thus was the science of astronomy extended and improved, in the hands of these celebrated men. But among all the schools of antiquity, in which this science was taught, that of Alexandria shown preeminent. This school collected, with intelligence and care, a crowd of observations made by its pupils, with trigonometrical instruments. At this school, too, were described, with care, the constellations; and it determined, in a precise manner, the position of the stars, and the course of the planets; and commenced an investigation of the inequalities in the movements of the sun and moon. Hipparchus here determined the length of the tropical year with greater precision than had been previously done—differing no more than about four and a half minutes from its true value.

Ptolemy, regarded as the first of astronomers, lived

in the second century of our era. He has transmitted to us, in his *Syntax*, a work of great labour, the observations and the principal discoveries of the ancients. He gave, in that work, the theory and the tables of the movements of the sun, the moon, the planets and the fixed stars. He had adopted the system which supposes the earth placed in the centre of the world, and to which his name has been given. The errours which his system embraced did not prevent this great man's calculating the eclipses which were to take place in the ensuing six hundred years.

The Syntax of Ptolemy was translated, about the year 826, of our era, by the Arabs, who gave it the name of *Almagest*. Four centuries afterwards this translation was rendered into latin, by order of Frederick II. Alphonso X, king of Castile, afterwards assembled the principal known astronomers, and caused them to prepare new tables, which are hence called *Alphonsine*.

This protection strikingly impressed the enlightened men of Europe. Astronomy was cultivated because it conducted to preferment, reputation and favours.—Treatises upon the science were multiplied, and with them the instruments which facilitated observations.—But the most remarkable event of this epoch is the reproduction of the ancient system of the world, discovered by Pythagoras. It was Copernicus, born at Thorn, in 1473, who resuscitated this system. He found that the system of Ptolemy, which supposed the earth fixed, and the sun, moon and planets turning, in concentrick circles, around this body, did not accord with observed phenomena; and he saw that the difficulties which encumbered that system would disappear in admitting that the sun is a centre, around which the earth, with the other planets, makes its annual revolution. This theory rests upon reasoning so incontestable that none other is now taught, or deemed worthy of

credence. Unfortunately Copernicus had not the satisfaction to witness the triumph of the doctrine which he had so well defended. Persecuted by zealots, and ridiculed by the learned, it was long after he had prepared the work in which he detailed his observations and discoveries, before he published it to the world.—When he finally did so, he lived to see a copy of the published work, but died a few days after.

The only serious opposition which the theory of Copernicus experienced was from Tycho-Brahe, the celebrated Danish astronomer, who combated the Copernican system of the universe, to make room for his own. His system differed little from that of Ptolemy; yet it bears the name of its Danish defender. He supposed that the earth was the centre of the world, and that the sun accomplished around it a revolution in twenty-four hours. The other planets, also, by this system, revolved round the earth in a peculiar and somewhat complicated manner. Some of his disciples, nevertheless, supposed the earth endowed with a diurnal motion upon its axis; and that the sun and all the planets made their revolutions round the earth in one year. We shall demonstrate the errour of this hypothesis in speaking of the system of Copernicus.

One of the scholars of Tycho-Brahe, namely, Kepler, added much to the rapid progress of astronomy. Hipparchus, Ptolemy, and even Copernicus, owed a great part of their knowledge to the Egyptians, the Chaldeans and the Indians: they all followed a beaten track. But Kepler was indebted solely to his own genius for those discoveries which have rendered him so celebrated: antiquity had bequeathed him no traces which indicated the route he pursued.

Galileo lived at the same epoch. While one of these great men traced the orbits of the planets and unveiled the laws of their movements, the other subjected to his researches the general laws of motion, which had been

two thousand years neglected. It was through the aid furnished by the labours of these two philosophers that Newton and Huygens were subsequently enabled to determine all the planetary movements. Galileo had demonstrated, in the most incontestible manner, that the earth had a diurnal and an annual motion; but this was contrary to the received doctrines of the day. The cardinals summoned him before them to answer for so grave a crime, and without regard to his age, his virtues, or his extended knowledge, they condemned him to perpetual imprisonment.

Since Newton, who greatly perfected it, astronomy has not ceased to be cultivated by men whose profound knowledge and valuable discoveries have greatly illustrated the science; but we have neither time or space farther to devote to this division of our subject.

## DEFINITIONS.

Astronomy treats of the movements, distances, magnitudes, physical constitution, eclipses and all other phenomena of the celestial bodies.

Under the general name of *stars* are vulgarly comprehended all those bodies, save the sun and moon, which deck the celestial spaces; but astronomy arranges them in several classes.

It distinguishes as *fixed stars* those which, in the revolutionary movement of the celestial sphere, appear always to preserve the same relative position; maintaining, among themselves, apparent invariable distances. To recognise these, and to designate them with greater facility, astronomers have divided them into groups, to which they have given the name of *Constellations*. Each of these has its particular denomination, derived from the name of a man, an animal, &c.; which is sometimes indicated by the form of the constellation itself, but is almost always capri-

ciously chosen. The utility of these denominations has perpetuated them among us. In order to distinguish from each other the individual stars of each constellation, they are classed according to their light, or apparent magnitude, giving to each a particular designation. The French mark the principal star of each constellation with a capital A; and the remaining stars are marked according to the method employed by John Bayer, in the celestial Charts which he published; which consists in designating each of them, in the order of its magnitude, by the letters of the Greek alphabet, commencing with $\alpha$ for the first or principal star, $\beta$ for the second, &c. If the number of letters in the Greek alphabet prove insufficient, the Roman alphabet is then substituted, after which, if there is still a deficiency, it is supplied by ordinary figures, 1, 2, 3, &c. This method has been generally followed by all modern astronomers.

Since, therefore, all maps and globes which exhibit the stars, will be found to have these Greek references attached to them, it is necessary that they should be within the reach of the student, and they are consequently subjoined.

THE GREEK ALPHABET.

| LETTER. | NAME. | SOUND. | LETTER. | NAME. | SOUND. |
|---|---|---|---|---|---|
| $\alpha$ | Alpha, | a | $\nu$ | Nu, | n |
| $\beta$ | Beta, | b | $\xi$ | Xi, | x |
| $\gamma$ | Gamma, | g | $o$ | Omicron, | o short. |
| $\delta$ | Delta, | d | $\pi$ $\varpi$ | Pi, | p |
| $\varepsilon$ | Epsilon, | e short. | $\rho$ $\varrho$ | Rho, | r |
| $\zeta$ | Zeta, | z | $\sigma$ $\varsigma$ | Sigma, | s |
| $\eta$ | Eta, | e long. | $\tau$ | Tau, | t |
| $\theta$ | Theta, | th | $\upsilon$ | Upsilon, | u |
| $\iota$ | Iota, | i | $\varphi$ | Phi, | ph |
| $\kappa$ | Kappa, | k | $\chi$ | Chi, | ch |
| $\lambda$ | Lambda, | l | $\psi$ | Psi, | ps |
| $\mu$ | Mu, | m | $\omega$ | Omega, | o long. |

Observations having detected the fact that certain heavenly bodies, aside from their apparent motion of diurnal revolution, were subject to another and actual motion, which caused the distances from them to surrounding stars to vary, thereby clearly showing that they changed places in the heavens, such were designated *errant stars*, or *planets*.

Primary planets may be defined opaque, celestial bodies, which revolve round the sun, as their centre, in orbits nearly circular, and which shine by the reflected light they receive from that body.

Beside the primary planets there are others, called secondary, or more commonly, *satellites* or *moons*, which revolve round some primary planet, as a centre, and are carried, with that planet, by attraction, in its revolution round the sun.

The primary planets are farthermore divided into *superiour* and *inferiour*. The superiour planets are those which are more elongated from the sun than is the earth: they are, Mars, Vesta, Juno, Ceres, Pallas, Jupiter, Saturn and Uranus: the inferiour are those whose distance from the sun is less than that of the earth: they are, Mercury and Venus.

It was proposed, by Herschel, to refuse the name of *planet* to Vesta, Juno, Ceres, and Pallas, on account of their diminutive size; but the proposition has not been generally sanctioned. These planets are not smaller, in comparison with Mercury, than Mercury is in comparison with Jupiter; and as they differ not, in other respects, they should manifestly bear the name planet—which is now generally accorded to them, as well defining their character, and avoiding unnecessary confusion.

The following are the names of the several planets now known to belong to our solar system, with the sign or character usually employed to designate each.

These are sometimes divided into ancient and modern; and we will, therefore, so distinguish them.

PLANETS KNOWN TO THE ANCIENTS.

| | |
|---|---|
| ☿ Mercury, | ♂ Mars, |
| ♀ Venus, | ♃ Jupiter. |
| ⊕ Earth, | ♄ Saturn. |

PLANETS DISCOVERED BY THE MODERNS.

| | | |
|---|---|---|
| ♅ Uranus, | ♆ | ⚵ Juno, |
| ⚳ Ceres, | ⚷ | ⚶ Vesta |
| ⚴ Pallas, | | |

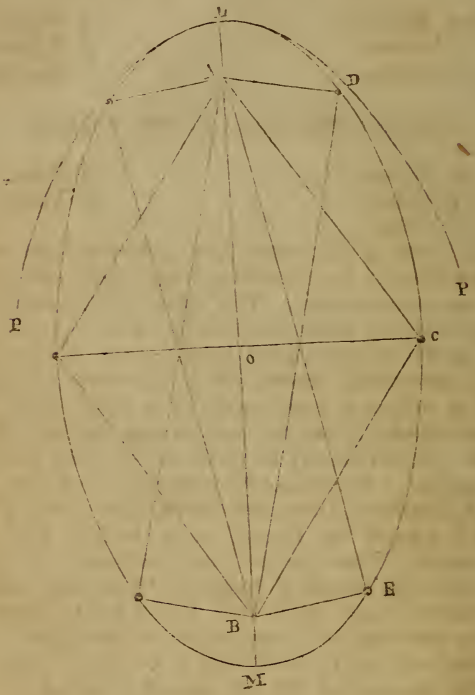
The *orbit* of a celestial body is the trajectory which it describes in its revolution round that body which serves it as a centre. The orbits of the planets are ellipses of very feeble excentricity; while those of comets on the contrary, have much greater excentricity, and consequently deviate much more from a circle.

The *ellipse* is any section of a cone, made by a plane oblique to, and not encountering the base of that cone. It may readily be produced by fixing firmly at two points, a thread, not fully extended, and then passing a pencil round these two points, all the while pressing it against the thread, so as to hold that fully extended. When the line thus produced, (the pencil having been guided, throughout, by pressing against the thread,) shall have been joined at all points, the curve thus obtained is that known as an ellipse.

Suppose, figure 17, A and B two fixed points, to which are attached the two ends of a thread, A C B, flexible, but not elastick, and longer than the interval A B. If this thread be extended by a fine point, C, its two parts will form, at pleasure, either the triangle A C B, in which A C and B C are equal; or the triangles A D B, A E B, &c., in which the sides A D

and B D, A E and B E, &c., will, on the contrary, be more or less unequal in proportion as the point shall be nearer to L or to M.

Fig. 17.




In passing from the right to the left of the line A B, the point, in its progress, will give rise to a series of triangles, similar to those upon the opposite side. In each of these series of triangles the sum of the dis-

tances of the moving point C, from the two fixed points A and B, will be always the same, for this sum constitutes the entire length of the thread.

Among all the positions through which the describing point, in this process, passes, there are two which merit our particular attention. They are those in which the triangles formed by the base A B and the two portions of the extended thread become straight lines; that is, when the describing point is either at L or M, in prolongation of the line A B.

We will first suppose the describing point at L. The thread is now extended, in a right line, from B to L; there it passes round this point and returns, in the same direction, from L to A, where the end was first fastened. In this position there are two portions of the thread, between L and A, applied to the same line; and the distance, therefore, from B to L is equal to the entire length of the thread, *less* the distance from A to L, through which, as we have shown, the thread is double. When the describing point is at M the circumstances are the same. From A to M the distance will be, likewise, equal to the length of the thread, diminished by the distance from M to B. Now M B cannot differ, in length, from A L, because the two ends of the curve must exactly correspond. Then, if to the distance B L, *which is less* than the entire length of the thread, by the quantity A L, we add either A L, or its equal, B M, the distance thus obtained will be that of the entire length of the thread. Thus A L, added to B L, gives us the distance M L; or, in other words, the distance of the two extreme positions of the describing point, situated upon the right line A B, is equal to the total length of the thread.

Geometricians call that curve which the point C thus traces an *ellipse*. Artists, gardeners, mechan-

icks, &c., call it an *oval;* and they are in the daily habit of producing it, in the manner here described.

This curve is elongated, in the direction of the right line which joins the points A B.

The points A and B are called the *foci of the ellipse.*

The line M L is the *transverse*, or *major* axis.

The points M and L, where the transverse axis touches the curve, are the *vertices.*

The point O, situated in the middle of A B, and consequently in the middle of M L, is the *centre* of the curve; but this term, *centre*, it must be borne in mind, has not the same meaning, here, as it has when applied to a circle, for all the parts of an ellipse are not equally distant from it, as those of a circle are.

The line extending across the ellipse, from C in the direction of O, and perpendicular to the line A B, is the *conjugate* or *minor* axis.

The distance between the centre, O, and the focus A; or the distance, which is the same, from O to the focus B, is called the *excentricity* of the ellipse; and the less this excentricity is, the nearer the ellipse approaches to a circle.

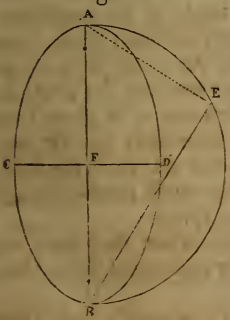
Let the points A and L, remain unmoved, and conceive the other focus, B, and the other vertex, M, to be removed, in the direction of the axis A B, to greater and greater successive distances. In that case these several new positions of B and M will correspond to new ellipses, all of which will enclose the first. When, by an abstraction which we realize in calculation, the focus B, is thus removed to an infinite distance; or, in other words, when the ellipse has an infinite transverse axis, it then takes the name of *parabola:* a curve which is not closed, but has two infinite branches, as P P. At L, and for some distance upon either side of this point, the two curves, the ellipse and parabola, nearly coincide. They both gradually depart farther

and farther from the line which joins the two foci; and in the case of the ellipse, the maximum of this distance is attained at the extremity of the conjugate axis. Beyond this the ellipse again approaches the grand axis, which it finally encounters at M. But it is not so with the parabola; the branches of which are separated farther and farther from each other, so long as their extension is continued. The deviation of one of these curves from the other becomes first sensible at a greater and greater distance from the vertex L, according as the transverse axis is more and more prolonged.

Any ellipse is said to be completely determined, when the two foci and the transverse axis are given; since, from these data, such ellipse may be produced. In proof of this it is only necessary to recollect that the transverse axis is the total length of the thread used in describing the ellipse, and that the foci are the two points where the ends of this thread are to be confined.

There is also a very simple rule by which to produce any ellipse of which the transverse and conjugate axes, only, are given. To illustrate this, suppose, Fig. 18, A B the given transverse axis, and C D the given conjugate axis. Then, to describe an ellipse whose axes shall be these given lines, first, from the centre, F, describe the semicircle A E B. Then apply the length of the conjugate axis, C D, from A to the point where that distance will touch the semicircle A E B. In this figure it touches at E. Then, from this point, draw the line E B, and the length of this line is

Fig. 18.



the distance between the foci of the ellipse required: in other words, the distance beween the two points at which the ends of the thread, whose entire length is A B, are to be confined.

The *ecliptick* is the orbit described, in appearance, by the sun round the earth, but in reality by the earth round the sun.

*Sensible horizon*, a circle which separates the visible from the invisible hemisphere; or the circle which is the boundary of our sight.

*Rational horizon* is a plane passing through the centre of the earth, and parallel to the sensible horizon.

*Azimuth*, is an arch of the horizon comprised between the meridian and the vertical plane which passes through an object.

*Colures* are ancient names by which we designate two great circles of the sphere, which pass, *that of the equinoxes*, through the equinoctial points and the pole of the equator; *that of the solstices*, through the solstitial points and the poles of the ecliptick and the equator.

*Terrestial longitude* is the angle of the meridians, measured by the arch comprised between them, upon the equator. The *longitude of a star* is the arch of the ecliptick comprised between that star and the point ♈.

*Terrestrial latitude* is the distance of a place from the equator, computed upon its meridian; and the *latitude of a star* is the distance of this star from the ecliptick, measured upon a great circle which passes through the star, and the pole of the ecliptick.

Two planets are *in conjunction* when they have the same longitude; and they are *in opposition* when their longitudes differ 180°.

*Declination* is the distance of a heavenly body from the equator, measured on a meridian; and it is either north or south.

*Meridian*, a great circle of the earth, passing through both poles; the plane of this circle extended to the sphere of the heavens, marks out the *celestial meridian:* the *plane of the meridian* is the plane of this circle; and its intersection with the sensible horizon constitutes a *meridian line*, or a north and south line from any given point to the horizon of that point.

The *zenith* is the summit of the celestial vault, the point directly over our heads, one of the poles of the horizon.

The *nadir* is the point opposite to that last described; the inferiour pole of the horizon.

The *Poles* are the extremities of the axis of a circle.

The *Nodes* are the points where the orbit of a planet cuts or crosses the ecliptick. The node from which a planet elevates itself towards the north, above the plane of the ecliptick, is the *ascending node;* that from which it descends towards the south is the *descending node;* and a line from one of these to the other is *the line of the nodes.*

The *Solstices* are the two extreme points of the sun's apparent excursion to the north and south of the equator.

The *Tropicks* are imaginary circles, parallel to the equator, which are touched by the sun at its greatest distance north and south, thus marking the limits of the torrid zone.

The *Sphere* is the apparent concave surface which surrounds our globe, and in which we seem to view the celestial bodies. This appears to turn upon the two poles.

*Apogee* is that point in the orbit of a planet where that body is at its greatest distance from the earth; and *Perigee* the opposite to this, or the point where it is nearest the earth.

The *Apsides* are those points in the orbit of a planet where that body is either at its greatest or least

distance from the sun or the earth. The first of these points, that is, the one most distant, is called the *Aphelion*, and the other *Perihelion*. The line which joins these two points, passing through the centre of the sun, &c. is the *line of the Apsides*.

*Syzygy* is the common denomination of the opposition and the conjunction of the moon, relatively to the sun.

The *Equator* is a great circle of which all the points are at an equal distance from the poles.

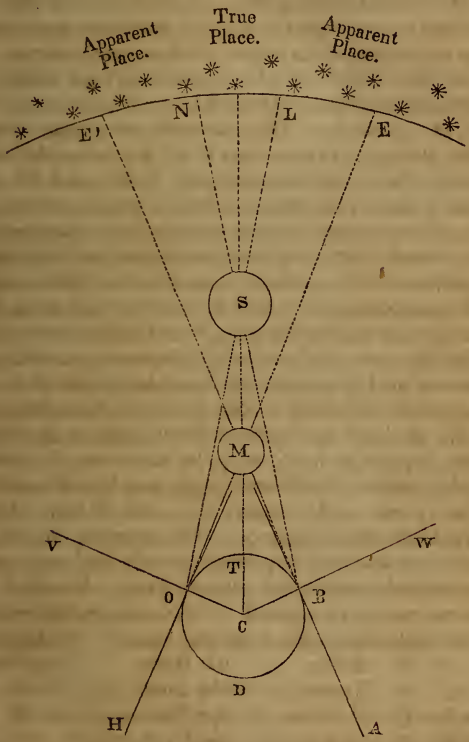
*Positions of the sphere* are its situations with reference to the horizon: they are *right*, *parallel* and *oblique*. The *right position of the sphere* is where the poles are in the horizon, and the equator is in the zenith. People on the equator, only, have this position. A *parallel sphere*, is where the equator coincides with the horizon, which is only at the two poles of the earth. In all other positions the sphere is oblique.

The *Parabola* is a section of a cone *cut parallel to the side of that cone*, and encountering its base: it is, consequently, an *open curve*, the two ends of which, by prolongation, would never meet. See page 52.

*Parallax* is the angle comprised between the directions in which a heavenly body would be seen, if viewed at the same instant from the centre of the earth and from a point upon its surface. In other words, it is the *apparent* change of place, of a heavenly body, caused by a *real* change of place of the observer, situated upon the earth. We will illustrate this by a diagram. Suppose the circle T O D B, fig. 19, to represent the earth, M the moon, S the sun, and E′ N L E a portion of the ecliptick. C would be the centre of the earth; O B two observers placed at these two distant points upon the earth, for the purpose of observing the parallax of two heavenly bodies; say the sun and moon. The line H shows the horizon of the observer, O, and the line V his zenith;

while the lines A and W, in like manner, denote those of the other observer, B. Then, the observer at O

Fig. 19.




would see the sun, among the fixed stars, at L, while the observer at B would refer the same body to the point N of the heavens. These two observations, then, would give different results, as to the position of

the sun, at the same moment; and this difference would be the total effect of parallax, with reference to these two positions; or the value of the angle O S B, formed by the rays O S and B S, at the centre of the sun. This angle once ascertained, we can determine therefrom the angle which either of these rays forms with the vertical line C S, and consequently we obtain the horizontal parallax of the sun.

So of the moon. The same observer, placed at O, refers the moon to the point E of the ecliptick; while the one at B, sees the same body at the point E'. By this it is shown that the parallax is greater, in proportion as the planet or star is nearer to the earth; in other words, that the *apparent* place of any one of these bodies differs more from the true place, under these circumstances. But it must be borne in mind that any one of these bodies, if situated in the zenith, or directly over the head of the observer, (as if he were stationed at T,) has no parallax, but is seen in its *true place*, as if viewed from the centre of the earth, at C.

The *Zodiack* is a zone of about eighteen degrees in width, divided in its breadth, by the ecliptick, into two equal portions. In its circumference it is divided into twelve parts, called *signs;* and each of these signs is divided into thirty degrees. The signs of the zodiack have each received a specifick name; and each is also represented, in celestial globes, maps, &c. by a certain character, or symbol. These are as follows:

| No. | Sign. | Latin name. | English name. | Degrees. |
|---|---|---|---|---|
| 0 | ♈ | Aries, | the Ram, | 0° |
| 1 | ♉ | Taurus, | the Bull, | 30° |
| 2 | ♊ | Gemini, | the Twins, | 60° |
| 3 | ♋ | Cancer, | the Crab, | 90° |
| 4 | ♌ | Leo, | the Lion, | 120° |
| 5 | ♍ | Virgo, | the Virgin, | 150° |
| 6 | ♎ | Libra, | the Balance, | 180° |
| 7 | ♏ | Scorpio, | the Scorpion, | 210° |

| No. | Sign. | Latin name. | English name. | Degrees. |
|---|---|---|---|---|
| 8 | ♐ | Sagittarius | the Archer, | 240° |
| 9 | ♑ | Capricornus, | the Goat, | 270° |
| 10 | ♒ | Aquarius, | the Water Bearer, | 300° |
| 11 | ♓ | Pisces, | the Fishes, | 330° |

These signs are situated in the order in which they are here named, proceeding from west to east; and this is designated *the order of the signs.*

The etymological explanation of these several names has given rise to numerous and protracted discussions, to which the researches of the *Institute of Egypt*, at Paris, have finally put an end, by showing that these names, now adopted by all people who devote any attention to astronomy, were drawn from comparisons made by the Egyptians between celestial and terrestrial phenomena, purely local, for the most part, and appertaining exclusively to a particular portion of their country. The following is an abridgment from the researches in question, which cannot fail both to interest and instruct.

### 1st. Sign of the Goat, (Capricornus,) ♑.

This is the first month of summer, and extends from the 20th of June to the 20th of July, about.

In Greek, Επιφι, επηφι, (according to Alberti, *Fabricii Menologium.*)

Coptick, *Epep, (Lexicon Ægyptiano-Latinum* of Lacrozc.)

Arabick, *Hebhebi, Hebheb.*

Latin. The definition of these several names may be thus rendered; *Caper, dux gregis, qui cœpit, species apparens aquæ, evigilatio, motio huc et illuc, aurora.*

The Arab word *hebheb*, or *habeb*, signifies *cœpit*,

*evigilavit, experrectus fuit e somno, flavit ventus, vacillavit, huc et illuc motus fuit, insiliit in favellam.*

The following is an explanation of the Latin phrases which have served as a translation of the ideas expressed by the Coptick and Arabick words.

*Caper*, the name Capricorn, Goat, one of the twelve signs of the Zodiack.

*Dux gregis, qui cœpit.* Capricorn opens, or commences the year; he is the chief of the Celestial animals, as, upon the earth, he is that of the flock of which he constitutes a part.

*Species apparens aquæ*, the commencement of the increase or flood of the Nile, which is not ordinarily appreciable until ten days after the solstice.

*Qui evigilavit, qui experrectus fuit e somno*, designates the longest day: the sun, or the animal which represents it, is awakened and roused at an hour which is consecrated to sleep in the other seasons of the year.

*Qui vacillavit, qui huc et illuc motus fuit*, the apparent hesitancy of the sun, in its motion, when arrived at the solstice.

*Qui flavit ventus*, a north wind which blows during fifteen days, at this epoch. The Egyptian almanacks note the period of its commencement.

*Aurora:* This proves that the Egyptian year commenced at this period. Finally, according to Herodotus, *Epiphi*, or *Epephi* was probably one of the twelve astronomical gods of the Egyptians, for he says, book II, chapter 38, that they esteem bulls as sacred to this deity.

2d. Sign of the Water Bearer, (Aquarius,) ♒.

This is the second month of summer, and extends from the 20th of July to the 20th of August.

Greek, Μεσορὶ, Μεσσορι, Μεσωρι, Μεσορη, *(Menolog.)*
Coptick, *Mesore.*

Arabick, Mesour, misr.

Latin, *Vas aquæ, paulatim lac suum reddens*

The Arabick word *meser* may be rendered *præbuit paulatim, emulsit quidquid esset in ubere.*

The addition of the *i* final, which personifies *mesouri*, causes it to signify aquarium.

*Paulatim lac suum reddens*, &c. coincides perfectly with the picture of the Water Bearer, in the Zodiacks of Essori and Denderah, where the vase, slightly inclined, suffers the water which it contains to escape, or overflow.

*Emulsit quidquid in ubere.* It is mostly during this month that the Nile pours out the bounty of her fertilizing waters. The Egyptians figuratively regard the waters of these inundations as milk, in sweetness and nutrition, so important are they to the fecundity of their lands. The inundation continues to increase during this month.

### 3d. Sign of the Fishes, (Pisces,) ♓.

This is the third month, from the 20th of August to the 20th of September.

Greek, Τωθ, Ϯωυθ, Ϯωϯι, φϯω.

Coptick, *Thoout.*

Arabick, *Thohout.*

Latin, *Ambulatio pisces, incessus, reciprocatus ultro, retroque in se rediens.*

The Arabick word *tona* may be rendered *peragravit regionem, opplevit puteum.* The *hout*, fish; *hat, circumnatavit.*

*Ambulatio*, &c. show us the fishes going and returning to and fro, in the waters which overflow and cover the country.

*Opplevit puteum*, designates the inundation spread over all the low grounds; for, at this time, it extends over all Egypt. Finally the festival of *Isis* is placed

at the commencement of this month, because it is only then that the people celebrated the festival of the Nile, or the opening of the dikes. It is for this reason that it has been sometimes called *fotouh*, *apertura per terræ superficiem fluentis aquæ*, opening of the dikes.

A passage of Sanchoniathon, preserved by Philo, says that *messori* gave birth to Thoth; and we see that it is *messori*, or the increase of the Nile, which produced *touhout*, the expansion of the waters upon the face of Egypt, in which the fishes were enabled to disport themselves over the fields.

### 4th. Sign of the Ram, (Aries,) ♈.

Aries is the first month of Autumn; commencing on the 20th September, and terminating on the 20th of October.

Greek, Φαωρι, παοφι, παωφι.

Coptick, *Paopi.*

Arabick, *Fofo*, *foafi.*

Latin, *Hœdus*, *velox*, *vox qua greges increpantur.*

The Arabick word is rendered by *increpuit gregem dicens fafa.*

The Hebrew word *fafa* signifies *obtenebrescere.*

*Vox qua greges increpantur.* As the waters of the flood withdrew from the land, the Ram once more conducted to the fields the flock of which he was the head, and which had been held in captivity by the waters, during the inundation.

*Obtenebrescere.* The increase of darkness, through the diminution of the length of days, from the autumnal equinox.

### 5th. Sign of the Bull, (Taurus,) ♉.

The Bull, second month of Autumn, from the 20th of October to the 20th of November.

Greek, Αθωρ, αθορι, (Θωωρ, *Eusebius.)*
Coptick, *Athor.*
Arabick, *Thaur*, *athour.*
Latin, *Taurus*, *Tauri.*
The word *athor* may be rendered *aravit*, *submovit terram*, in reference to the season of ploughing, which, in Egypt, does not commence until seed time is past, in some other countries, in the month of November.

### 6th. Sign of the Twins, (Gemini,) ♊.

The Twins, third month of Autumn, from the 20th of November to the 20th of December.
Greek, Χοαχ, χοιαχ, Κοαχ, Κηκος.
Coptick, *Choiak.*
Arabick, *Chouk.*
Latin, *Amore flagrantes*, *amatores.*
In the Egyptian zodiacks this sign is indicated by the figures of a young man and a young woman: during this month seed grain, which has been sown, swells and germinates: it was therefore an errour of the Greeks to name this sign, as they did, διδυμοι, the Twins, as the emblems employed by the Egyptians were intended to indicate the season of fecundity.

### 7th. Sign of the Crab, (Cancer,) ♋.

Cancer is the first month of winter, from the 20th of December to the 20th of January.
Greek, Τυβι.
Coptick, *Tobi.*
The word *teby* may be rendered *amovit*, *avertit;* and the word *teb*, by *reversus*, *conversus fuit*, *respuit.*
These roots well characterize the retrograde movement of the sun, at the solstice of winter.

8th. Sign of the Lion, (Leo,) ♌.

The Lion, second month of winter, from the 20th of January to the 20th of February.

Greek, Μεχιρ, Μεχειρ, Μεχος.

Coptick, *Chery* or *Mechery.*

The word *cher* may be rendered *acquisivit, collegit; mecher* by *pars segetis;* or *mecher* by *protulit frondes, ramos; amcher*, by *plantas suas extulit terra inflatus, turgides fecit.*

All this is typical of the fact that, it is in the month of February that, in Egypt, the earth presents its most rich and imposing features, some part of the harvest being then commenced. It is by a figure of the king of beasts that the Egyptians here typically personified the force and ripening magnificence of nature, at this important period.

9th. Sign of the Virgin, (Virgo,) ♍.

This is the third month of winter, from the 20th of February to the 20th of March.

Greek, Φαμενωθ.

Coptick, *Famenoth.*

Arabick, *Faminoth.*

Latin, *Mulier feconda et pulchra, quæ vendit spicam, frumentum, et quod portatur inter duos digitos.*

This word is composed of *famij*, a vender of the ears of grain, of every kind, of which the ears or the stalks can be carried between two fingers, and of *Enoth*, a handsome, fruitful woman. In the Egyptian zodiacks *Famenoth*, or the fruitful woman, holds an ear of grain in her hand. The Greeks were induced to the errour of naming this sign παρθενος, the Virgin, by the fact that the Egyptian word conveys the idea of *endowed with beauty;* but that word also as distinctly conveys the idea of *fecundity*—the typical signification

of which, no less than the sense itself, the Greeks in this instance neglected or overlooked.

10th. Sign of the Balance, (Libra,) ♎.

The Balance, first month of spring, from the 20th of March to the 20th of April.

Greek, Φαρμουθι

Coptick, and Arabick, *Faramour;* which may be rendered by *mensura, regula confecta temporis.*

This word has reference to the vernal equinox, and the consequent equality in the length of the days and nights.

11th. Sign of the Scorpion, (Scorpio,) ♏.

The Scorpion, second month of spring, from the 20th of April to the 20th of May.

Greek, Παχων.

Coptick, *Pachous.*

Arabick, *Bachony.*

This word is composed of *bach,* rendered *prostravit, humi stravit,* which, in all the eastern languages, signifies *putruit; læsit, pravis fuit,* or *putrido, malum, morbus;* and of *honniy,* rendered *venenum, aculeus Scorpionis et terror.*

The original here, is significantly characteristick of the second month of spring, when the increasing heat calls forth venomous beasts and reptiles from their retreats, to roam over the land; and also develops maladies and pestilence. The root *hama* signifies, also, *ferbuit dies;* the days are become burning, or torrid.

12th. Sign of the Archer, (Sagittarius,) ♐.

The Archer, third month of spring, from the 20th of May to the 20th of June.

Greek, Παῦνι, παωνι.

Coptick, *Paons.*

Arabick, *Faync* or *fenni.*

Latin, *Extremitas seculi temporis, horæ. Faijnan, fenan,* may be rendered *nomen equi, Onager varii cursus.*

The root *fann* signifies *propellit, impulit; faijni* signifies *propulsator, impulsator.*

*Extremitas,* last month of the Egyptian year.

*Nomen equi. Onager,* name of a quadruped. *Propulsator* indicates its action. In the Egyptian Zodiacks the figure of this animal has the body of a quadruped, and a head with two faces, the one of a lion, and the other of a man. The man is armed, and in the act of letting fly an arrow. This compound being seems driving before him the animals in his front, while, with the other face, he frowns back those which appear to follow him. All indicates that this figure is typical of the close of the year, and that it is thus represented as having achieved its course.

## CHAPTER THIRD.

### ASPECT OF THE HEAVENS—APPARENT MOTIONS OF THE CELESTIAL BODIES.

Upon casting our eyes upward, in the open air, we behold spread out above our heads a vast concave hemisphere, of which we seem to occupy the centre, and which appears, in descending upon every side, to unite itself to the horizon. During the day this immense vault is enlightened by a brilliant disk, which, issuing from the regions of the east, moves majestically upward until noon, and then descending, upon the opposite side, is lost to our view, at evening, below the horizon in the west. The feeble light which now remains is soon extinguished, and then appear, upon every side, in the immensity of space, a multitude of brilliant points, of various magnitudes, and of which the number increases as the obscurity of night becomes more profound. The motion of these bodies adds still farther to the beauty of the scene. While some of them, moving in the same direction as the sun, sink behind the western horizon and disappear; others, rising in the east, pass over the celestial vault, and disappear, in their turn, where the sun was so recently lost to our view. All, however, do not thus disappear from us, for there are those which, in their entire revolution, sink not below our horizon, but of which we may follow the motion during the whole night: and there is one which appears at all times immoveable. On the other hand, while some describe immense circles, in the heavens, others pass over but a small arch of the horizon; while still another class do no more than just appear, and then immediately sink again beyond our sight. Such are the phenomena of the rising and setting of the stars. It is to this general move-

ment of the starry sphere, a single entire revolution of which is accomplished in a day and a night, or in twenty-four hours, that the name of diurnal motion has been given.

In this revolution of the sphere, the heavenly bodies, subject to the motion we have described appear, at first sight, to preserve among themselves the same relative distances from each other. But more precise observations do not fail to show that, if this is true of the greater part of these bodies, namely, that the relative positions of them, and their respective distances asunder are subject to no appreciable change, yet that some few of them are endowed with an actual motion, peculiar to themselves, which transports them successively from one constellation to another. It is this movement, or displacement among the stars, that we call the proper motion of the planets.

The sun, like the planets, is endowed with a proper motion; since we see it rise and set successively, in different points of the horizon. At the end of June it rises far north, remains a long time above the horizon and at noon approaches nearer to our zenith; while at the end of December it emerges from the horizon at a point much farther south, rises not, at midday, so near to our zenith, and describes, in the heavens, but a small circle above the horizon. It is to this movement that we are indebted for the variety of the seasons, and the inequality in the length of our days and nights.

The motions of the moon, and the aspects which it presents, at the different periods of its course, are still more remarkable. This body first shows itself or becomes visible, as *new moon*, in the western part of the heavens, at a short distance from the sun, under the form of a crescent, which increases in size in proportion as the moon elongates itself from the sun, by passing eastward in its orbit, until at length this body ri-

ses in the east at the same moment the sun is setting in the west. This is the period of full moon; and the face or disk of that body is then exactly circular. Continuing its movement eastward, it rises later and later each night, until it approximates the sun in the east, as it did, at new moon, in the west. It then shows itself, in the morning, a little before, or west of that luminary, as, in the first part of its course, it did in the west, a short distance behind, or east of him. These diverse phases all succeed each other in the course of a lunar month, to be repeated, in the succeeding one, in the same order.

Sometimes, indeed, we observe in the heavens luminous bodies totally different from any of those which have hitherto occupied our attention; and which, from the various changes to which they are subject, have ever been objects of curiosity and astonishment to the people. Small, and but slightly luminous, when first visible, they nevertheless soon assume considerable dimensions, and often exhibit a luminous tail like appearance, of which the extent and brightness are very variable. These bodies are Comets. They are endowed with a proper motion, the direction of which, unlike that of the planets, is susceptible of material change. As these bodies approach the sun they increase in light, and sometimes the train becomes greatly lengthened, more luminous, and more distinctly defined. As they recede from the sun both their light and magnitude decrease more or less rapidly, until they finally disappear, entirely, from our view.

In reflecting upon this revolutionary motion of the sphere, two questions very naturally present themselves to the mind, namely, does each star always accomplish its revolution in the same time? and, is its motion uniform; or, in other words, does it pass over equal spaces in equal times?

For the solution of the first of these queries it is sufficient to direct towards any star, whatever, a telescope, immoveably fixed, in some convenient position. By computing, accurately, the time which elapses until the reappearance of the same star in the telescope, we easily assure ourselves that the duration of the revolution is absolutely the same, whenever tried, and whatever star may have been employed for the observation. The space of time which elapses between two consecutive returns of a star to the same meridian, constitutes the *siderial day.*

The second question is resolved by means of an apparatus designated a *parallactick instrument.* It is composed of a graduated circle, fixed to a central axis, perpendicular to its plane; the prolongation of this axis confounds itself with the diameter of another moveable circle, which is constantly maintained perpendicular to the first; this second circle, furnished with a telescope susceptible of assuming any inclination, in reference to the central axis, in turning upon this axis, gives motion to a pointer which indicates, upon the first circle, the horizontal arches which it has passed over. Let us suppose this telescope directed towards some star which is constantly visible, (for it is necessary, for this, that the star be not lost sight of, during its entire revolution,) the axis of the instrument being parallel to that of the heavens, and a motion be communicated to the moveable plane, corresponding to the motion of the star. This done, if we note, with rigid accuracy, the intervals of time which elapse while the moveable plane passes over equal arches of the fixed plane, we shall find that these intervals are equal to each other. In order, then, to appreciate the quantity of a star's motion, or displacement, we may take, indifferently, either the measure of the arch it has described, or the time which it employed to describe it, after having once established, between these two data a

known and definite relation. Thus, the sphere accomplishing its revolution in twenty-four hours, and all the diurnal circles being divided into three hundred and sixty degrees, the stars are found to pass over fifteen of these degrees during each hour. But it must be recollected that these different circles are not all equal, that their divisions, therefore, do not coincide, and that, to compare the results, it is necessary to determine their relative value.

It is a very common errour, extensively accredited, that any of the stars may be seen, in day-light, from the bottom of a well. They cannot generally be seen, during the day, except with the assistance of telescopes, or by ascending high in the air, upon some elevated mountain, or in a balloon. This is not true of the *planets*, whose light is much more considerable; and Venus, for example, may often be seen, with the naked eye, and in open day, while the sun is still many degrees above the western horizon, although she is always in the same quarter of the heavens as that luminary. The reason of our inability to see these bodies, in day-light, with the naked eye is, the rays of the sun, reflected in every direction by the atmosphere, form a kind of luminous curtain, through which the light of the stars, being comparatively very feeble, is unable to penetrate. It is sufficient, indeed, that, of two lights, in presence of each other, one of them be sixty times more intense than the other, in order to render the lesser light imperceptible to the eye. This fact may be verified by a very simple experiment: place between two lighted candles, a body which will project two shadows; then remove one of the candles to such a distance that the light which it sheds upon the intermediate body may be only one sixtieth of what it was at first: a result easily produced, when it is recollected that the intensity of light is in the inverse ratio of the square of the distances. The

shadow produced by the light thus removed will not be visible, while at rest; but if motion be given to it, the shadow will then become perceptible. This is the principal reason why, with optical instruments, the stars are visible in full day; for these magnifying instruments, augmenting prodigiously their distances, accelerate, by the like quantity, their motions.

Aside from the proper motion of planets and comets, by which these bodies are distinguishable from the fixed stars, there is another difference which can hardly fail to be noticed by all. This is a scintillation, or rather twinkling which is peculiar to the fixed stars, and which consists in a change of intensity, accompanied by a change of colour, of these stars. The better to appreciate this it is necessary to refer to a remarkable discovery, recently made, in the properties of light. If we cause to fall upon the same point two luminous rays, having the same origin, they will not always add to the quantity of light; but it will sometimes happen, if the rays be caused to pass over different distances, or through mediums of different densities, that, in certain conditions, these two rays, instead of aiding, destroy each other; so that we may produce, however singular the result may appear, obscurity by adding light to light. This is the phenomenon of *luminous interferences;* and it is by it that the twinkling of the fixed stars is explained. The different parts of the atmosphere being subject to a continual variation of density, realizes the conditions of the phenomenon of interferences, and intercepts, thus, some of the rays which compose the white light of the stars, leaving others to reach our eye, which can only produce a feeble and diverse coloured image. The planets do not exhibit this appearance, because they have a visible surface, of appreciable extent.

The aspect of the heavens varies with the position of the observer. Suppose he occupied exactly one of

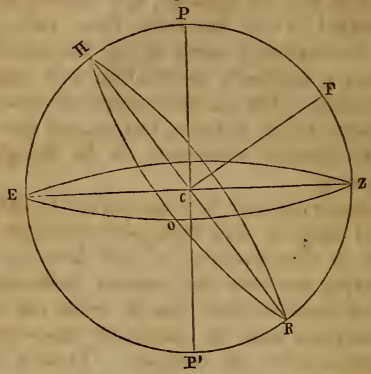
the poles of the earth; for example, the north pole. In that position his zenith will be the celestial north pole, and his rational horizon will coincide with the equator. All the stars having a northern declination, that is to say, all those which are comprised between the north pole and the equator, will appear to describe circles parallel to the horizon; those occupying the equator will constantly move in the horizon, while all those having a southern declination will remain constantly invisible. The parallelism of all these motions, with reference to the horizon, has caused this position, as we have already remarked, to be designated the parallel sphere.

Let the observer now be transported to the equator: his rational horizon will then pass through both the poles, and, in this position, he will have all the stars in view during the time they employ in describing one half their diurnal circles, that is, while the sun is below the horizon, and the planes of these circles will be perpendicular to the horizon. This is the right position of the sphere.

If the observer now proceed from the equator towards one of the poles, the north pole, for example, this pole will appear to elevate itself gradually above the horizon, and the south pole will be depressed below the horizon, in the same proportion. Suppose, for example, that he has proceeded thirty degrees towards the arctick pole, his zenith will be C F, fig. 20. The great circle, H O R, will be his horizon; the plane of the equator, E O Z, will be elongated from the zenith, F, thirty degrees, and consequently will be distant from the horizon sixty degrees. The pole, P, will be elevated thirty degrees, measured by the angle H C P, and the pole P′ will be abased, by an equal quantity, below this plane. It follows, from this demonstration, that the distance from the zenith to the equinoctial, or the *latitude*, is always equal to the height of the pole

above the horizon. In this position the circles described by the stars are inclined to the horizon; from which circumstance this position is called the oblique sphere.

Fig. 20.




In following the course of the stars of the sphere we have seen them all successively elevate themselves above the horizon and subsequently sink below it. At what point, then, do the stars cease to ascend? and how shall we determine, accurately, that point? There are several methods which conduct to this result: the following, founded upon *the correspondent heights of the sun*, is, perhaps the most simple.

Upon a surface exactly horizontal (which is to be determined by means of the ordinary spirit level) erect a stile that shall be strictly perpendicular, and around the foot of this, as a common centre, describe several circles, of different diameters. Then, on each of these, mark carefully, and accurately, before and after noon, the exact point at which the extremity of the shadow that is cast by the stile, touches upon that circle. By dividing the arch comprised between the two points

which the shadow has traced upon each circumference, we obtain a line which, passing through the foot of the stile, determines the plane in which the sun was situated, when it had attained the highest point of its course. This instrument is called a *gnomon*, and the plane which it serves to determine is the *meridian*. It passes through the zenith of the place, and through the poles; and a right line traced upon the earth, in this plane, is a *meridian line*, and cuts the horizon at the same point as the celestial meridian.

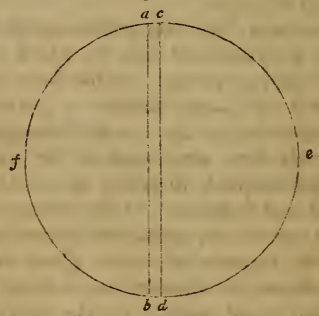
Another method, also very simple, is that of *the measure of time;* but it is necessary for this purpose, to make use of a transit instrument, or meridian telescope, which, as it is frequently employed by astronomers, we will describe.

This instrument, like the astronomical telescope, is composed of a cylindrical tube to which are fitted an object glass and eye piece. At the focus of the object glass is placed an opaque screen or partition, having a small perforation in the centre, through which the central or axis rays may pass to the eye, while all others are intercepted, in order to render the vision more perfect and defined. At the same point are disposed, upon moveable, metallick mounting, some exceedingly fine threads of metal, glass or other substance, which are so adjusted as to divide the field of view into four equal parts. In the *micrometer* these threads are usually five in number, placed vertically and parallel, while a sixth is adjusted horizontally, at right angles to these. The transit instrument, fixed firmly upon trunnions, is so constructed as to be immoveable, except only in a vertical plane.

To determine the meridian, place the instrument in a vertical plane, direct the telescope to some star which is constantly visible, through its whole revolution, observe the respective instants of its greatest and least elevation, and count, by a very exact and well regula-

ted clock, the time which elapses between the two passages of the star. Usually, however carefully we may have chosen the plane, there will be found a great difference in the time consumed by the star, in passing over the respective distances between these two points, and upon opposite sides of them; the one requiring more time than is demanded by half a revolution, that is, more than twelve siderial hours, and the other less. It will suffice, then, to know this difference, and to adjust the instrument in that plane which will divide, exactly into two halves, the diurnal circle of the star; which may easily be done by successive trials. To illustrate this, suppose *c f d e*, fig. 21, the diurnal cir-

Fig. 21.




cle of the star; and that, at the first trial, the transit instrument be adjusted in the vertical plane *a b*. The star will then consume less time in passing through *a f b*, than it will in passing through *b e a*. But when the instrument is subsequently adjusted in the vertical plane *c d*, which, passing through the centre of the diurnal circle, divides it exactly into two halves, the time through one will then be exactly the same as that through the other.

There are, also, different methods by which to fix and determine the position of the stars. Of these, two are more particularly employed.

The first consists in measuring the angles formed by vertical planes passing through each star, with a meridian to which is referred the distances of these stars.

It is commenced by determining the height of the observed star in the vertical plane in which it is placed, by the aid of the quadrant of a mural circle. This is a sector, furnished with a moveable telescope, at the focus of which is fixed a micrometer, composed of two moveable threads, only; one vertical, the other horizontal. The radius of the circle should be disposed vertically, in the plane of the meridian, and should correspond to zero of the divisions traced upon the dial plate described by the radius. The vertical thread of the micrometer serves to direct the optical axis in the plane of the radius, an indispensable condition, in order that the arches measured by the limb may be equal to those described by the optical axis. From the moment that the axis enters into the field of the telescope, by means of convenient machinery, it is made to follow the horizontal thread, and when its centre touches the vertical thread it is exactly in the plane of the meridian. Then read off, upon the graduation, the arch which the angle formed by the vertical radius and the visual radius measures, and this angle is the distance to the zenith; the complement of the meridian altitude.

It is next requisite to know the angle comprised between the vertical in which the observed star is situated, and the meridian: this angle is called the azimuth of this star; and it is eastern or western. It may be arrived at by noting exactly the time of its passage of the meridian, and in the vertical where it is observed: then the time which elapsed between these two passages, will give its value. This method, which is quite simple, has been very frequently employed.

The zenith distance and the azimuth of a star, elements necessary to fix its position, may also be obtained

by the aid of an instrument composed of two graduated circles, of which the horizontal one will indicate the meridian line, and the other, furnished with a telescope and micrometer, is perpendicular to the first, and moves round a vertical which passes through its centre. When a star is to be observed, bring it to the centre of the cross threads, having previously carefully adjusted in its vertical plane the circle last mentioned. It will indicate, then, the height of the star above the horizon, and its distance from the zenith, which is its complement, while the horizontal or azimuth circle marks the azimuth, at the moment of the observation.

The zenith distances and the azimuths form, then, as we see, a system of angles, by the aid of which it is very easy to obtain the position of the stars, in a rigorous manner. But this method presents an inconvenience, in practice, which has caused it to be almost entirely rejected: which is, that the zenith and the azimuths varying as often as the observer changes his horizon and his meridian, there remains no fixed point to which we are able to refer all the observations, and the different positions offer no common point of comparison. It is for this reason that the following, known as the method of determining *the right ascensions and the declinations of the stars*, is now generally preferred and practised.

By this process it suffices to know the hour circle of the star, and its position upon this circle. The position of the star, upon the hour circle, is determined by the instrument which serves us to measure meridian altitudes; and the star's declination is its distance from the equator, reckoned upon its hour circle: hence we sometimes call these, *circles of declination.*

Declination is reckoned from zero to 90°, or a right angle; and we call it *northern*, or *southern*, according as the star is north or south of the equator.

As to the position of the hour circle, it is determined by the angle which it makes with a designated hour circle. If the angle formed by the intersection of these planes is measured by an arch of the equator, this arch is what we designate the *right ascension.* It is determined by observing the time which elapses between the moment when the star passes the meridian, and the passage of the hour circle which has been chosen as the point of departure. Astronomers designate by the sign ♈ the point from which to reckon the right ascension of the stars; and this point is that where the sun crosses the equator, when it ascends from the southern tropick towards the north.

Right ascension, then, is the angle which the hour circle of a star forms with the meridian, at the instant when the fixed point of Aries, ♈, the point where the sun appears to us to enter upon spring, is in the plane of the meridian. Right ascension is always computed from west to east, upon the equator, and from zero to 360°, or the entire circumference. This system of lines, by which we determine the position of the stars, offers, as will be readily perceived, much analogy with the preceding, yet it differs essentially in this, that the positions of the stars being taken with reference to circles of the celestial sphere which are invariably fixed, (for, indeed, they are no other than the celestial equator and a fixed meridian,) all the observers situated upon the surface of the earth are enabled to refer their observations to these, and to compare with each other the results they have obtained. The declination and right ascension once known, we readily find all the relations of situation and of distance upon the celestial sphere.

What we have shown upon this subject will be sufficient to make known how we are enabled to obtain a catalogue of the stars, by means of a meridian telescope or any other convenient instrument. We first

determine the instant in which any star, whatever, which we know, passes the meridian; and we note exactly the hour, minute and second of its passage. We do the same with each of the other stars, in succession, as they arrive in the plane of the meridian. In this manner we determine their right ascensions, and at the same time the exact height or declination of each one of them. These data once acquired, it is easy to indicate the position which they should preserve, relatively to each other; and thus we should have a celestial chart, upon which would be traced the different groupes of stars which form the constellations.

The first celestial charts are very ancient. Hipparchus is the first who is known to have constructed them; and as the relative distances of the stars have undergone no sensible change since the earliest observations, these charts may always be employed in a study of the heavens.

The point at which we commence to compute right ascension, serves us also for that of siderial time; that is to say, we count 0h 0′ 0″ siderial time; at the moment of its passing the meridian.

From this is seen that nothing is more easy than to know the hour, in siderial time, the height of the pole in the place where one observes being previously known. It suffices to observe the zenith distance of a known star, and to calculate its hour angle, computing, for example, from the superiour meridian, and in the direction of the diurnal motion, from 0° to 360°, adding this angle to the right ascension of the star, and rejecting the entire circumferences, if any. The remainder, converted into time, will express the distance of the meridian from the point of the heavens that has been assumed as the point of departure, that is to say, the siderial hour.

# CHAPTER FOURTH.

## OF THE FIXED STARS.

We have already stated that under this general denomination are comprised all the celestial bodies which appear to maintain, invariably, their relative positions. We say *appear*, because modern observations, particularly those of Herschel, father and son, Bessel, Struve, &c., show changes in their mutual relations from which it is certain that some, at least, of the fixed stars, have proper motions, though apparently so slow as to be almost imperceptible. Among those fixed stars which appear but single to the naked eye, there are many that, in the telescope, under a high magnifying power, are resolved into two or more stars, lying but little out of the right line of vision, although perhaps often at very different distances from us. These are called *double*, *triple*, or *multiple* stars, according as they may be resolved into two, three, or more; and their number is very great. A catalogue of these, but embracing only those of a certain description, and extending no farther than to 15° of southern declination, was published by Prof. Struve, of the Dorpat Observatory, Russia, in 1827, that contains the places of no less than 3112 of these stars.

Motion is detected in some of these, which, although called *fixed*, are found to have regular revolutions around each other, in well defined orbits. The number of such now certainly known, is about forty; although observations have by no means been so numerous, upon this subject, as to enable us to fix their number at no more than this. Among these may be noticed $\zeta$ of Cancer, and $\xi$ of Ursa Major, which have nearly completed an entire revolution since they were first observed; and $\eta$ of the Crown has probably made more than one such revolution; while Castor, $\gamma$

of Virgo, $\sigma$ of the Crown, 70 of Ophiuchus, and 61 Cygnus are unquestionably of this class, and have changed their positions remarkably. The last of these, from observations made as late as 1838, is believed to accomplish its revolution in something more than 540 years.

The number of the fixed stars at first appears immense, because they are confusedly scattered over the celestial sphere, and cannot all be embraced, at once, in the field of vision. But it is easy to convince ourselves that the number of those visible to the naked eye is very limited, and does not exceed, at most, a few thousands. This may be shown by taking any one portion of the heavens separately, and counting all the visible stars it contains: they will be found but few; yet, by the assistance of telescopes their number may be multiplied beyond all known limits, save that of the size and power of the instrument employed.

Their distribution in the heavens, in groups or clusters, probably suggested the first idea of dividing them into constellations. We have already seen that these are systems of stars distinguished from each other by letters and figures. Hipparchus has transmitted to us a general table of the constellations which were known in his time. They were 48 in number: 12 in the zodiack, 21 northern and 15 southern. Since his time their number has been considerably augmented.

The following table contains the names, both classical and English, of the several constellations, and the number of stars that each contains, according to the respective catalogues of Ptolemy, Tycho-Brahe, Hevelius and Bode. The Nebulæ in each, as far as determined, are also noted; though improved telescopes may very probably much augment the number of these, as they doubtless will, and in some instances already have, that of the stars themselves.

| CLASSICAL NAMES OF THE CONSTELLATIONS. | ENGLISH NAMES OF THE CONSTELLATIONS. | Number of Stars in Ptolemy's Catalogue. | Tycho-Brahe's Catalogue. | Heveleus' Catalogue. | Bode's Catalogue. | Nebulæ. |
|---|---|---|---|---|---|---|
| **NORTHEN, ANCIENT CONSTELLATIONS.** | | | | | | |
| Ursa Minor, | The Little Bear, | | | | 26 | |
| Ursa Major, | The Great Bear, | 35 | 29 | 73 | 156 | 4 |
| Draco, | The Dragon, | 81 | 32 | 40 | 126 | 2 |
| Cepheus, | Cepheus, | 13 | 4 | 51 | 98 | 10 |
| Bootes, | Bootes, | 23 | 18 | 52 | 125 | 2 |
| Corona Borealis, | Northern Crown, | | | | 26 | |
| Hercules, | Hercules, | 29 | 28 | | 89 | 4 |
| Lyra, | The Harp, | 10 | 11 | 17 | 39 | 2 |
| Cygnus, | The Swan, | 19 | 18 | 47 | 112 | 18 |
| Cassiopeia, | Cassiopeia, | 13 | 46 | 33 | 55 | 12 |
| Perseus et Caput Medusæ, | Perseus and Medusa's Head, | 29 | 29 | 46 | 95 | 6 |
| Auriga, | The Charioteer, | 14 | 9 | 40 | 79 | 10 |
| Ophiuchus, | Serpent Bearer, | 29 | 15 | 40 | 124 | 13 |
| Serpens, | The Serpent, | 18 | 13 | 22 | 84 | |
| Aquila, | The Eagle, | 15 | 19 | 42 | 85 | 5 |
| Delphinus, | The Dolphin, | 10 | 10 | 14 | 26 | |
| Equuleus, | The Little Horse, | | | | 15 | |
| Pegasus, | TheWinged Horse, | 20 | 19 | 38 | 14 | 1 |
| Andromeda, | Andromedia, | 23 | 23 | 47 | 62 | 10 |
| Triangula, | The Triangles, | 4 | 4 | 12 | 19 | 1 |
| Coma Berenices, | Berinece's Hair, | 14 | 14 | 21 | 65 | 6 |
| **NORTHERN, MODERN CONSTELLATIONS.** | | | | | | |
| Leo Minor, | The Little Lion, | 35 | 14 | 21 | 49 | 4 |
| Canes Venatici, | The Grayhounds, | | 2 | 23 | 39 | 1 |
| Sextans, | The Sextant, | | | | 40 | |
| Cerberus, | Three headed Dog* | | | v | | 2 |
| Taurus Poniatowski | Bull of Ponatowski, | | | | 13 | |
| Vulpecula et Anser | The Fox and Goose | | | 29 | 44 | 9 |

*This Constellation was formed, by Heveleus, from part of Hercules; and it is still, by many, treated as part of that constellation. It is sometimes figured, in maps and upon globes, as a three headed dog, and at others as three serpents, in the left hand of Hercules.

| CLASSICAL NAMES OF THE CONSTELLATIONS. | ENGLISH NAMES OF THE CONSTELLATIONS. | Number of Stars in Ptolemy's Catalogue. | Tycho-Brahe's Catalogue. | Hevelius' Catalogue. | Bode's Catalogue. | Nebulæ. |
|---|---|---|---|---|---|---|
| Lacerta, | The Lizard, | | | 10 | 21 | 3 |
| Musca Borealis, | The Northern Fly, | | | | 8 | |
| Tarandus, | The Rain Deer, | | | | | |
| Custos Messium, | The Guardian of the Harvests, | | | | 10 | 1 |
| Camelopardalis, | The Cameleopard, | | | 32 | 58 | 3 |
| Lynx, | Lynx, | 25 | 25 | 38 | 76 | 1 |
| | CONSTELLATIONS OF THE ZODIACK. | | | | | |
| ♈ Aries, | The Ram, | 18 | 21 | 27 | 54 | |
| ♉ Taurus, | The Bull, | 44 | 43 | 51 | 210 | 8 |
| ♊ Gemini, | The Twins, | | | | 106 | 10 |
| ♋ Cancer, | The Crab, | 23 | 15 | 39 | 112 | 1 |
| ♌ Leo, | The Lion, | | | | 172 | 10 |
| ♍ Virgo, | The Virgin, | 32 | 33 | 50 | 233 | 18 |
| ♎ Libra, | The Scales, | 17 | 10 | 20 | 68 | 1 |
| ♏ Scorpio, | The Scorpion, | 8 | 8 | | 89 | 7 |
| ♐ Sagittarius, | The Archer, | 31 | 14 | 22 | 174 | 24 |
| ♑ Capricornus, | The Goat, | 28 | 28 | 29 | 101 | 1 |
| ♒ Aquarius, | The Water Bearer, | 45 | 41 | 47 | 139 | 4 |
| ♓ Pisces, | The Fishes, | 38 | 36 | 59 | 140 | 2 |
| | SOUTHERN, ANCIENT CONSTELLATIONS. | | | | | |
| Cetus, | The Whale, | 22 | 21 | 45 | 127 | 7 |
| Eridanus, | The River Po, | 34 | 10 | 27 | 97 | 4 |
| Orion, | Orion, | 38 | 42 | 62 | 107 | 21 |
| Lepus, | The Hare, | | | | 20 | 2 |
| Canis Minor, | The Little Dog, | 2 | 5 | 13 | 21 | 1 |
| Canis Major, | The Great Dog, | 29 | 13 | 21 | 39 | 8 |
| Argo Navis, | The Ship Argo, | 45 | 3 | 4 | 136 | 4 |
| Hydra, | The Water Serpent | 27 | 19 | 31 | 100 | |
| Crater, | The Cup, | 7 | 8 | 10 | 21 | 1 |
| Corvus, | The Crow, | 7 | 4 | 4 | 23 | |
| Centaurus, | Centaur, | 37 | | | 70 | |
| Lupus, | The Wolf, | 19 | | | 32 | |
| Ara, | The Altar, | 7 | | | 5 | |
| Corona Australis, | Southern Crown, | 13 | | | 12 | |
| Piscis Australis, | Southern Fish, | 18 | | | 27 | |

| CLASSICAL NAMES OF THE CONSTELLATIONS. | ENGLISH NAMES OF THE CONSTELLATIONS. | Number of Stars in Ptolemy's Catalogue. | Tycho-Brahe's Catalogue. | Hevelius' Catalogue. | Bode's Catalogue. | Nebulæ. |
|---|---|---|---|---|---|---|
| SOUTHERN, MODERN CONSTELLALIONS. | | | | | | |
| Fornax Chemica, | Chymists' Furnace, | | | | 37 | |
| Reticulus Rhomboidalis, | The Rhomboidal Net, | | | | | |
| Apparatus Sculptoris, | The Sculptor's Tools, | | | | 17 | 1 |
| Dorado vel Xiphias, | The Sword Fish, | | | | | |
| Horologium, | The Clock, | | | | 11 | 1 |
| Norma Euclidis, | Euclid's Square, | 24 | 10 | 20 | 9 | |
| Circinus, | The Compasses, | | | | | |
| Triangulum Australe, | Southern Triangle, | | | | | |
| Columba Noachi, | Noah's Dove, | | | | 38 | |
| Equuleus Pictorius, | Painter's Easel, | | | | | |
| Monoceros, | Unicorn, | | | 19 | 59 | 30 |
| Pyxis Nautica, | Mariner's Compass, | | | | 10 | |
| Autlia Pneumatica, | Air Pump, | | | | 23 | |
| L'oiseau Solitaire, | Bird of the Desert, | | | | 18 | 1 |
| Crux, | The Cross, | | | | | |
| Musca Australis, | Southern Fly, | | | | | |
| Chamelïon, | The Chameleon, | | | | | |
| Piscis Volaus, | Flying Fish, | | | | | |
| Telescopium, | The Telescope, | | | | 25 | 2 |
| Apus, vel Avis Indica, | The Bird of Paradise, | | | | | |
| Mons Mensæ, | Table Mountain, | | | | 19 | |
| Scutum Sobieski, | Sobieski's Shield, | | | 7 | 12 | 11 |
| Indus, | The Indian, | | | | | |
| Pavo, | The Peacock, | | | | | |
| Octans, | The Octant, | | | | | |
| Microscopium, | The Microscope, | | | | 17 | |
| Grus, | The Crane, | | | | | |
| Touchana, | American Goose, | | | | | |
| Hydrus, | Water Snake, | | | | 10 | |
| Cela Sculptoria, | Engraver's Tools, | 12 | 13 | 16 | 18 | |
| Phoenix, | Arabian Bird, | | | | 7 | |
| Sceptrum, | The Sceptre, | | | | 9 | |

Kepler has made a very ingenious observation upon the magnitude and distances of the fixed stars. He remarked that there are but thirteen points upon the surface of a sphere which can be equally distant from each other, as they are from the centres: and supposing that the fixed stars nearest to us are equally as elongated from each other as they are from the sun, he drew the conclusion that there are, rigorously speaking, but thirteen stars of the first magnitude. At twice the distance from the sun, there may be four times as many, and so on, in succession. This method of calculation gives us very nearly the numbers of the stars of the first, second and third magnitudes.

In a serene night, when the stars are wholly unobscured, there are distinguishable, in several parts of the celestial sphere, whitish patches, of different sizes and forms, which shed but a feeble light. On directing a powerful telescope to any one of these, we discover a multitude of small stars, apparently very near each other; and it is the light emitted by these that causes the appearance of which we have spoken. The *Milky Way*, that luminous zone of the celestial concave, is nothing else than a series of nebulæ of this kind. Herschel speaks of them in these terms: "These nebulæ are arranged in layers extending a very great distance, and I have sufficiently surveyed some of them to determine both their form and their directions. It is probable that they entirely surround, or traverse the starry sphere, like the Milky Way, which is certainly no other than strata of these stars: and as this immense starry bed is not equally luminous, in all its parts, as it runs not in a right line, but is curved, and even divided into several zones, we may presume, with much reason, that there is great variety in the layers of these masses of stars and nebulæ. One of these beds is so rich in stars that, in one of its parts, which I carefully observed, only thirty-six minutes, I dis-

covered thirty-one nebulæ, all distinctly visible, in a perfectly serene night. Their situations, their volume and their light offered a diversity hitherto unknown. In another strata, which is, perhaps, a different branch of the first, I have often seen double and triple nebulæ, variously arranged; some appearing surrounded by a multitude of small bodies, like attendants; in others the nebulous light was narrow, but much extended; again this was in the shape of a fan, resembling an electrick brush, issuing from a luminous point; others were of the cometick shape, with a seeming nucleus in the centre; or, like cloudy stars, surrounded with a nebulous atmosphere; a different sort, again, contain a nebulosity of the milky kind, like that wonderful, inexplicable phenomenon about $\theta$ of Orion; while others shine with a fainter, mottled kind of light, which denotes their being resolveable into stars.

It is probable that the great stratum, called the Milky Way, is that in which the sun is placed, though perhaps not in the very centre of its thickness. We gather this from the appearance of this galaxy, which seems to encompass the whole heavens, as it certainly must do, if the sun is within the same. For, suppose a number of stars arranged between two parallel planes, indefinitely extended every way, but at a given considerable distance from each other; and calling this a siderial stratum, an eye placed somewhere within it will see all the stars in the direction of the planes of the stratum projected into a great circle, which will appear lucid on account of the accumulation of the stars, while the rest of the heavens, at the sides, will only seem to be scattered over with constellations, more or less crowded, according to the distance of the planes, or the number of stars contained in the thickness or sides of the stratum.

We are now able to appreciate the place which our little planet occupies in this vast universe. Take a

single star of that immense system, and compare it to the innumerable quantity of the stars; and, in order to form a more correct judgement, examine it, at first, with the naked eye. The stars of the first magnitude, being probably nearest to us, furnish us the first degree of our scale: consequently, if we take the distance of Sirius or of Arcturus, for example, for unity, we may suppose that those stars of the second magnitude are at double the distance of these, while those of the third magnitude are at treble the distance; and so of the rest. If we admit that a star of the seventh magnitude is about seven times as distant from us as one of the first, an observer placed in the centre of a sphere surrounded by stars could not discern the most distant parts of the stellary system, with the naked eye, because, according to our estimate, such view could not extend beyond seven times the distance of Sirius, while the utmost limit of this system may be adjusted at, perhaps, very many times such distance.* The visible universe of such an observer would only include the constellations, with all the stars that accompany them; unless, indeed, the night be one of unusual serenity, without clouds, haze, or other obstructions to vision, in which case some of the principle nebulous stars are sometimes discernible. But furnish this individual with a telescope of only moderate power and he readily suspects that the *Milky Way* is but a vast accumulation of stars, a suspicion which is soon converted into certainty, by a farther augmentation of the power of his instrument. The numerous nebulæ,

*In this extract it has not been deemed expedient to change the language in which Herschel has clothed his fanciful theory respecting the fixed stars; and it is therefore necessary to advise the pupil that this theory, namely, that those fixed stars which appear the largest are nearest to us, cannot be true unless all those bodies are of the same magnitude, and emit the same quantity of light—of which there does not exist the least proof; nor has the supposition even probability in its support.

also, scattered through the heavens, and, for the most part, visible only through the aid of telescopes, are likewise composed of clusters of stars, whose individual light, by reason of their proximity, is thus blended in one common mass."

Herschel observed the Milky Way with much attention, and he found that in its lightest portions the stars were immensely numerous. He states, (what seems impossible to know,) that in one quarter of an hour he once saw there one hundred and sixteen thousand stars pass across the field of view of his telescope, which had an aperture of only 15′; and that, at another time, in a period of only forty-one minutes, he thus counted 258,000! With him, as with all subsequent astronomers, each successive improvement of the telescope, in size and power, has added to the number of stars actually observed; so that their number, and the extent they occupy, seems bounded only by the limits of the Universe.

Our sun is probably no other than one of the fixed stars; since, if it were removed from us to the distance which it is known the fixed stars must be, it would present to us the same appearance as those bodies do. Hence we may conclude that these stars, which shine by their own light, since their distance is so enormous that it is impossible for them to receive their light from our sun, as the planets of our Solar System do, are comparable to our sun, both in brilliancy and volume; that their distances from each other are equal to their distances from us: and finally, reasoning from what we know of the mechanism of the heavens, that, like our sun, these bodies dispense light and heat to planetary systems which gravitate around them, but which, from their immeasurable distance, are rendered invisible to us.

Herschel thought that our sun has a direct progressive movement, in space, towards the constellation

Hercules, carrying, of course, with it, our entire planetary system. He remarked that the apparent motions of forty-four stars, out of fifty-six which he had carefully examined, were very nearly in the direction which would produce a real movement of this kind, in the solar system, and that the brilliant stars Sirius and Arcturus, have, as they should, if this theory be true, the greatest apparent motion. The star Castor, when viewed through a telescope, is shown to be two stars, of about equal magnitude; and although they may have an apparent motion, it has not been possible to detect a variation of a single second in the distance between them; and yet, this would be very easily done, if their apparent movement were owing to a real, progressive motion of our sun, through the regions of space, as Herschel supposed.

In examining, with care, the catalogues of the stars which have been left us by the ancient astronomers, as those of Ptolemy, Tycho-Brahe, Heveleus, &c. we are struck with several very singular facts; namely, some of the stars have changed, more or less, their quantity of light; others have appeared, as *new stars*, where none had been known before, while others, still, have disappeared, entirely; some to return subsequently to view, with all their former brilliancy, and others that, when once lost sight of, have since been nowhere seen. These astonishing and inexplicable phenomena have not been confined to any particular period, but have been manifested at various, and distant times, according to the testimony of different witnesses, who have recorded the facts they have observed. Halley, the English astronomer, gave a very interesting account of these phenomena, which was published in the Transactions of the Royal Society of London, in the year 1715. The following is abridged from that publication. "The new star in the chair of Cassiopeia was not seen by Cornelius Gemma, on the 8th of No-

vember, 1572, although he says he that night examined that portion of the heavens, with care, during a very serene sky; but on the following night, November the 9th, it appeared with a splendour which surpassed all the fixed stars, and fell but little short of that of Venus. This was not seen by Tycho-Brahe until the eleventh day of the same month; but from that time he assures us that it gradually decreased and died away until, at the end of sixteen months, namely, in March, 1574, it was no longer visible. Its position in the heavens, according to the observations of Tycho-Brahe, was, in right ascension, 9° 17′, and northern declination 53° 45′.

On the tenth of October, 1604, the scholars of Kepler discovered another new star, in the right leg of Serpentarius. It was not visible the previous night, but shone out, almost at once, with a lustre surpassing that of Jupiter. This, like the former one, faded gradually away, and finally disappeared entirely, in January, 1606. These two new stars seem to have differed, materially, from any others. Neither of them had either tail or envelope, as comets usually have; nor had they any parallax; from which it is known that they were at a greater distance than any of the planets. But between these two periods, namely, in 1596, David Fabricius discovered another of these singular variable stars. It was situated in the neck of the Whale, and at the time of its greatest brilliancy equalled that of a star of the third magnitude. This body has since been found to exhibit periodical changes in the intensity of its light. But although variable in its appearance, it never becomes wholly extinguished, but continues always visible, with the aid of the telescope. No star was known, in the heavens, resembling this in variableness, until the discovery of such an one in the neck of the Swan. Its right ascension was 1° 40′; southern declination 15° 57′. A new variable star

was discovered in the neck of the Swan, in the year 1600, by W. Janson. This did not exceed a star of the third magnitude; and after continuing for some years distinctly visible, it became so much diminished that it was thought, by many, to have entirely disappeared; but during the years 1657, 1658, and 1659, it gradually rose again to a star of the third magnitude. The period of its variation of magnitude is fixed, by modern astronomers, at about eighteen years. The right ascension of this star was $9^s$ 18° 38′; declination north, 55° 29′ minutes. In July, 1670, a fifth new star was first seen and observed by Hevelius. It then appeared like a star of the third magnitude, but by the beginning of October it was hardly to be seen, with the naked eye. In April following it was again as bright as before, or rather greater than a star of the third magnitude, and yet it wholly disappeared about the middle of August, of the same year. The next year, in March, 1672, it was again visible, but it did not then exceed a star of the sixth magnitude; and since that period it has not been seen. The position of this star was, in right ascension, $9^s$ 3° 17′; and northern declination 47° 28′. The sixth is that which was discovered by G. Kirch, in the year 1686. Its period of change was determined to be 404½ days; and although it rarely exceeds in size, a star of the fifth magnitude, yet it is very regular in its returns, as was carefully observed, in the year 1714. On the 15th of June, 1715, after long and careful watching, with a good telescope, it was perceived, and in appearance it resembled one of the very least telescopick stars. During the remainder of that month, and the July following, it increased so that in August it was visible to the naked eye, and thus remained until the end of September. After that it again diminished, by degrees, and on the 8th of December, at night, it was scarcely discernable, by the aid of a telescope. It

was seen, in all, this year, about six months, which is but little less than half its entire period. The time of its greatest brightness is about the 10th of September; and its position is, in right ascension, $9^s\ 6°\ 30'$; declination north, $52°\ 40'$."

The star Algol, also, is a very remarkable body, belonging to the class of periodical stars. It changes, continually, from the first to the fourth magnitude; and the time employed, from its greatest to its least magnitude, and including the interval of time in which it experiences no change, is a little less than three days. From its full splendour, as a star of the second magnitude, it is reduced to one of the fourth, in a little more than three and a half hours; it then increases, for a like period, when it again arrives at its former magnitude. These peculiarities were discovered by John Goodricke, who first began to observe them about the end of the year 1782, and they have been fully confirmed by subsequent astronomers. Those stars which, in the last century, were suspected to be variable, are divided into two classes: in the first class are placed all those which are really changeable; and in the second, such as were only presumed to be so. The first class embraces twelve in number, from the first to the fourth magnitude; comprising that which appeared in Cassiopeia, in 1572, and the one of 1604, in Serpentarius. The second class numbers thirty stars, of from the first to the seventh magnitude.

Ingenuity has been exhausted in endeavours to explain these surprising changes. Newton supposed that the temporary augmentation of the light of these stars arose from an augmentation of combustible materials, by the fall of some comet upon the body of the star. This system of Newton, which assumed that comets are destined to become fuel, wherewith to feed the combustion of our and other suns, as we add wood or coal to a fire, to perpetuate it, is certainly

very little in harmony with the means which nature elsewhere employs, or with the now more generally received probability of the electrical nature of the combustion of the celestial bodies. Maupertuis supposed that these stars are endowed with a rotary motion, upon their axis, so rapid that the centrifugal force has given to them the figure of an exceedingly flattened spheroid; or rather, reduced them to a circular plane, with broad side surfaces, and having little thickness. Possessing this shape, a star might sometimes, by the position of its axis, present to our view the broad face of its disk, and at other periods, by a change in the position of its axis, would be reduced to a minute speck, as it were, by a presentation of its thin edge, only, to the eye of the observer. Others have thought that these changes were produced by dark spots upon the surfaces of the stars; and others, still, have suggested that these immensely distant bodies revolve in orbits so vast that, like comets, they are only visible to us while traversing those regions of their path which lie nearest to us. The prevailing opinion of the best astronomers, in regard to these periodick stars, now is, that only part of their surfaces are enlightened, and that, consequently, each one, in revolving upon its axis, alternately presents to us sides more and less illuminated; thus causing the *apparent* size of the body itself to vary.

From the facts already adduced, in relation to these distant bodies, a reflection very naturally arises respecting our own sun. That body, as we have already said, is a star; and it differs from others in apparent size, by being placed much nearer to us in space. Has this body ever undergone any of these, or analogous variations? And if it has experienced any of these great vicissitudes, what incalculable consequences may have resulted to our earth therefrom? These considerations should, perhaps, command the attention of

such geologists as seek for the causes of those tremendous catastrophes of which our globe furnishes, in almost every part, so many traces.

It remains for us, in closing this chapter, to form, if possible, some idea of the distance which separates us from the fixed stars. Before entering upon this problem, however, some previous explanations are indispensable.

The angle subtended by any object varies in the inverse ratio of the distance of the object from the eye of the observer. This is one of the most elementary propositition in geometry; and is daily illustrated, in the observation of objects upon the earth, around us.

On the other hand, trigonometry makes known the relations which exist between the dimensions of an object, its distance, and the angle which it subtends: thus, an object which subtends an angle of 1° is at a distance equal to $57\frac{3}{10}$ times its size; if the angle is of 1′, the body is at the distance of 3438 times its size; and it is at the distance of 206,000 times its size, if the angle subtended is one of 1″.

This being understood, it is easy to see that, the diameter of the earth being known, if we can know the angle which it subtends; in other words, its apparent size, when viewed from the stars, this fact would disclose to us the distance of those bodies. It is this angle which we designate parallax. For finding it we employ a method analogous to that for measuring the distances between terrestrial objects. This consists in assuming a base line, of a known extent, and then measuring the angle formed, at each extremity of this line, by the visual rays from the object in question. These angles ascertained we substract their sum from 180°, and the remainder will give the angle sought, according to that well known and fruitful proposition in geometry, namely, that *the three angles of a triangle are always equal to two right angles, or* 180°.

Proceeding in this way, and when we assume, as a base line, the *radius*, or even the *diameter* of the earth, the parallax thus obtained is not appreciable, in the case of the fixed stars; by which we know that the diameter of the earth, compared to the distance which separates us from the fixed stars, constitutes but an imperceptible quantity.

But, because neither the radius of the earth, which is about four thousand miles, nor its diameter, which is about eight thousand, is a distance sufficient to furnish us any parallax upon the fixed stars, a more extended base line has been resorted to, by astronomers, for that purpose. The mean distance of the earth from the sun being ninety-five millions of miles, it follows that the diameter of the earth's orbit must be twice this sum, or *one hundred and ninety millions of miles.* The particular points in space, then, which the earth, in its annual journey round the sun, occupies upon any two given days which have an interval of half a year between them, must be the entire diameter of this orbit, or one hundred and ninety millions of miles, in a right line one from the other. Of this immense distance astronomers, by allowing intervals of six months between their observations of the stars, have contrived to avail themselves, as a base line. This is known as the *great, or annual parallax;* and the highest hopes were entertained that the plan would determine the distance of the fixed stars. Several astronomers observed, with the greatest care, and with suitable instruments, at the vernal and autumnal equinoxes, the passage of the star $\gamma$, of the Dragon, little doubting that the diameter of the earth's orbit would give, by this mode of observation, an appreciable angle. But their hopes were disappointed: no angle was perceived. And yet, if an angle of only one second of a degree, (1″,) had been found, this would show us that the star in question is one hundred thousand times one hundred and

ninety millions of miles from the earth; and yet we should be enabled to measure its volume! We know, then, that this star is *farther* from the earth than this immense distance, but *how much* farther we have not the means to determine. What subject of contemplation so suitable as this to aid us in forming a conception of the immensity of the celestial spaces, especially if we suppose, as we justly may, that the thousands of stars which decorate the heavens, have spaces between themselves, some of which, at least, are equal to their distances from us? Not only may this justly be supposed true, but it is even indisputable, notwithstanding that the stars, to an unreflecting observer, *appear* to be all situated upon a common surface. The reason of this is that every celestial object is referred, by us, to the inner surface of an immense hollow sphere, of indefinite radius, having our eye for its centre. This sphere, and consequently our horizon, *we always carry with us*, in all our change of place, upon the earth. Whatever our course may be, stars that, *in front of us*, were below our horizon, at starting, constantly rise to view, and elevate themselves more and more, as we advance, *while behind* us, such stars as were in sight at first as constantly sink below the horizon, and disappear; and all this while the imaginary sphere, of which we have spoken, is found to have moved with us, and still, as at first, to have our eye for its centre, and consequently, to be divided through that centre by the plane of our horizon.

Observations upon the fixed stars, of a later date than those referred to above, and made, too, with instruments still farther improved, have been more successful. Professor F. W. Bessel, of the Konigsberg Observatory, in October, 1838, communicated to the publick that he had been able to obtain an annual parallax upon the double star 61 of the Swan, amounting to $0'.3136$. This places that star at the distance of

657700 times ninety-five millions of miles from the earth; and light, which moves with a known velocity, employs ten years and three tenths to traverse this distance.

In addition to the stars already noticed, as having vanished from sight, some of the European Astronomers, in 1839, published to the world the then recent disappearance of no less than *nine* other small stars, whose places, in the heavens, had thus been left vacant. These changes are wholly inexplicable to us, in the present state of our knowledge; and they only bear witness to us of the extraordinary activity of nature, in these elongated portions of the universe.

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## CHAPTER FIFTH.

### DISTANCES, ETC. OF THE PLANETS.

However great the magnifying power of the telescopes we employ may be, the apparent diameter of the fixed stars is never augmented. They always appear as an indivisible point. The planets, on the contrary, present a disk, of which the diameter increases with the magnifying power of the telescope we employ. These facts are alone sufficient to convince us that the planets are much nearer to us than the fixed stars; while the micrometer proves to us that each of their distances varies, one time with another, by disclosing to us variations in their apparent dimensions.

The moon, which by the same means is shown to be still nearer the earth, was early submitted to the appreciations of geometry. In 1751 Lacaille and Lalande, two French astronomers, proceeded, the one to Berlin, and the other to the Cape of Good Hope, for the purpose of determining the parallax of this body, and thereby fixing its distance from us. The pupil is

already informed that parallax is the angle formed by two visual rays departing from a planet or star, and terminating at the two extremities of the terrestrial radius. They found this angle, in the case of the moon, to be 1°, which gives, for the mean distance of the moon from the earth, about sixty times the earth's radius, or 240,000 miles. The diameter of the moon is a little more than one quarter that of our earth, and its volume is about one fiftieth that of the same planet.

It is possible that an errour may exist, in the estimate of the moon's distance, by this method, amounting to half a second in each of the angles measured at Berlin and at the Cape, and consequently of one entire second, in the result, amounting to the three thousand six hundredth part of the entire distance, of 240,000 miles. The possibility of this amount of errour, in all observations of this nature, is unavoidable, since angles cannot be thus measured with greater certainty.

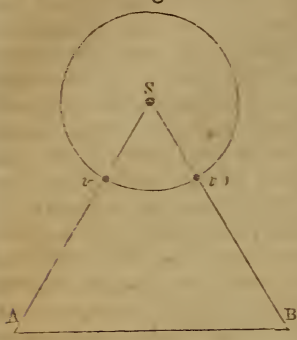
The parallax of the sun is $8'\,,6\frac{1}{10}$ nearly, and its mean distance from the earth, ninety-five millions of miles, in round numbers. Its diameter is, to that of the earth, as 1 to 111, and its volume is in the proportion of 1 to 1,300,000.

The parallax of the sun is known to one tenth of a second, very nearly; an approximation to the truth much greater than can be obtained by the measure of angles, as above described. This valuation, then, has been obtained by a different method; which we now proceed to explain.

This knowledge is furnished by the passages of the planet Venus across the disk of the sun. Let S, Fig. 22, be the sun, A B the radius of the earth, and v v′ the planet Venus moving in its orbit round the sun. Now suppose two observers placed, one at A and the other at B, to observe and note, exactly, the different phases of the conjunction; the difference of their results would show the time which Venus consumed in pass-

ing over that portion of its orbit between v and v', and from this, though by a method too complicated to be presented here, is deduced the parallax of the sun. This operation, which we have attempted to present here, in its utmost simplicity, is, in practice, encumbered with difficulties arising from the constant motion of the earth, and various other particulars, all of which it is necessary rigidly to estimate and consider, in order to obtain a true and accurate result.

Fig. 22.




The distances and the volumes of the other planets have been determined by analogous means; and we shall give the results of these, severally, while treating of each planet separately, in the subsequent parts of this work. However, we will here make known the singular numerical relations which exist among the distances of the planets, with regard to each other. If we take the following numbers, namely, 0, 3, 6, 12, 24, 48, 96, 192, and to each of them we add the number 4, so as to obtain the following series, namely, 4, 7, 10, 16, 28, 52, 100, 196, these last quantities are found to express the order of the distances of the planets from the sun, as follows:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0, | 3, | 6, | 12, | 24, | 48, | 96, | 192. |
| 4, | 7, | 10, | 16, | 28, | 52, | 100, | 196. |
| ☿ | ♁ | ⊕ | ♂ | ♃ | ♀ | ♄ | ♅ |

This singular proportion of the planetary distances, from the sun, is known as *Bode's law*, it having been discovered by the late Professor Bode of Berlin.

From the extent of space between the orbits of Mars and Jupiter, by which this law was very greatly violated, that astronomer suggested that a planet was there wanting, and which might hereafter be found. Within the present century the four telescopick planets, namely, *Vesta*, *Juno*, *Ceres* and *Pallas* have been discovered, all revolving between Mars and Jupiter, and in orbits situated so nearly the same as to answer, very well, the requirements of this law. These facts early led to a strong presumption that the law in question was not the result of accidental circumstance, but one which entered essentially into the structure of the Universe: and such presumption seems now reduced to entire certainty by the still more recent discovery that secondary planets, no less than primary, are adjusted at distances which are in conformity with this law. "This law," says Delambre, "which is not, indeed, very rigorously exact, is purely empirical, and no one is able even to suspect what its foundation may be." Investigations subsequent to those of Delambre, however, have probably given us farther insight to this interesting subject. The late L. W. Caryl believed that, in 1837, he demonstrated the law in question to be one of those upon which rests the stability of the Solar System. If his demonstrations were not erroneous, then many of the planetary inequalities which now exist are due to the slight deviations, in the positions of the several planetary orbits, from a rigid observance of the law in question; and, farther, had the observance of this law been but slightly less than we find it to be, in those positions, the Solar System could not have maintained its place and adjustment, but must have gone to pieces, by the action of its several parts upon each other.*

* Mr. Caryl died while still pursuing this interesting investigation; and it is not known that his papers, in relation to it, were left in a condition to be available to others. He was a resident of Buffalo.

### THE SUN, ☉.

We have seen that the sun is an immense globe, 1,300,000 times greater than the earth which we inhabit, and that its mean distance from the earth is 95,000,000 of miles. We shall learn, in a future chapter, that attraction furnishes us the means of determining its density, and its weight. We have already stated that, in the opinion of Herschel, this immense body is probably carried, with all the planets which revolve around it, through the regions of space, towards the constellation Hercules. Be this as it may, it certainly has a rotary motion upon its axis, by which it completes a revolution in twenty-five days. This is proved by observations made upon the spots which its surface presents, and of which we shall speak more fully when treating of the physical constitution of the sun. The peculiar motions of these spots, and the different aspects which they assume, according as they present themselves obliquely, or directly in front, leave us no room to doubt that they pertain inherently to the surface of the sun; while they prove to us, incontestably, that the sun itself is a spherical body. We speak not, here, of the movement which the sun appears to execute, in the plane of the ecliptick; for this, as the pupil will learn, in a subsequent part of this work, is the result of the translation of the earth, through the different parts of its orbit.

### PHYSICAL CONSTITUTION OF THE SUN.

The sun, as has been stated, presents spots upon its surface. Some of these are dark, and others luminous, but all differing, materially, in appearance, from the general complexion of the sun. Their forms are very irregular, and their duration exceedingly variable; and they are usually surrounded by a penumbra, or

imperfect shadow. They are almost always comprised within a zone of which the extent varies, north and south of the solar equator; most of them, however, falling within the width of 60°. The appearance of these spots, when viewed through a good telescope, is often similar to that in the annexed diagram.

Fig. 23.

Suppose *a b c*, Fig. 23, the sun, and *d e f* spots upon its disk; the interiour portions of which are black, while the surrounding penumbra is of a lighter shade.

Much ingenuity has been expended in endeavours to explain the nature and character of these spots. Some have imagined that the sun, from which a great quantity of heat and of light are constantly emanating, is a body in constant combustion, and that the dark spots are masses of scoria, or dross, floating upon its surface. The bright spots, on the contrary, have been attributed to a species of volcanick eruption of this mass of melted matter. The objection to this opinion is, that it does not furnish an explanation of the appearances presented by the sun; and consequently it has not obtained the assent of astronomers. The

theory which, at the present day, is received with the most favour, is that which considers the sun as composed of a dark and solid nucleus, surrounded by two atmospheres, the one dark and the other luminous. Upon this hypothesis the appearance of the spots is explained by supposing changes produced in the atmospheres, which expose to view the dark body of the sun. The penumbra is the dark atmosphere, the fissure in which is supposed to be less than that in the luminous one, and which consequently remains visible around the borders of the opening which exhibits to us a portion of the sun's nucleus.

This opinion, however whimsical it may appear, has the advantage, at least, of explaining perfectly all the phenomena; and it acquires a high degree of probability when we consider that the incandescent matter of the sun can be neither a solid nor a liquid, but is, necessarily, a gas.

Luminous rays, emanating from a solid or liquid sphere, highly heated, manifest the property of polarization, while those escaping from incandescent gas are deprived of this property. It is the application of this principle to the experiments made upon the rays of the sun, which has conducted to the conclusion above stated, respecting one of the physical conditions of the sun.

These experiments are made by means of a very ingenius instrument, the principle of which rests upon the properties of polarized light. This instrument is a species of telescope, so arranged as to give two coloured images of the sun, when pointed at that body. A very simple mechanism enables the observer to separate these images, entirely, or to superimpose one upon the other, either wholly or in part, at his pleasure. This instrument seems to determine that the light from the borders of the sun is equally as intense as that from the centre; for, if we superimpose the two images

of the sun in such a manner that the border of one image coincides with the centre of the other, a perfectly white light will be produced at this point of coincidence. From this fact it follows: 1st, that the borders of the sun yield light equally as intense as that from its centre; and, 2d, that the colours of the two images, produced by the telescope, are complementary one of the other.

But from this fact, namely, that the light from the borders of the sun is equally vivid as that from its centre, there results another consequence. It is, that the sun has no atmosphere outside of its luminous covering, for, if it were otherwise, the light from the borders of the sun, having a thicker layer of this atmosphere to traverse, would thereby become more enfeebled.

What is the nature of the sun's light? This question has long divided philosophers. One class of these, supported by the authority of Newton, supposed that the sun, as well as all luminous bodies, has the property of launching forth, with prodigious velocity, very minute particles of its own substance; this is known as the system of *emission*. Others, on the contrary, suppose that the phenomenon of light is produced by the vibrations of a fluid called ether, which is every where distributed throughout nature, and is put in motion by the presence of luminous bodies: this is known as the system of *vibrations* or *undulations;* and it is the one now generally received; for no person can understand how a body can continually emit portions of its particles, and yet lose none either of its volume or its light. But the most serious and fatal objection to the system of emission is that it does not, in the present state of our knowledge, furnish an explanation of all the conditions of the case; while the other theory has all probabilities in its favour, particularly since recent discoveries have shown the most

intimate relations between the cause which produces the electrical phenomena and those which result in the production of light.

Pouillet, a French philosopher, has devised a very ingenious method of determining the temperature of luminous rays. His method is the following: Suppose, says he, a sphere of ice, with an opening sufficient for the introduction of a thermometer to its centre; which instrument we will suppose to be stationary there, at zero. Then, if luminous rays be admitted through the opening, and suffered to fall upon the thermometer, the mercury of the instrument will ascend in the tube, and thus indicate the augmentation of heat received from the rays. Now, if we know the distance of the thermometer from the luminous body, the proportion that the opening through which the rays are admitted bears to the entire circumference of the sphere, and the quantity, in degrees and parts, which the ascent of the mercury, in the instrument, indicates, we may then calculate the quantity of heat which is produced by the body from whence the luminous rays have proceeded. In this way, whatever may be the distance of the luminous body, provided that distance be known, the mean quantity of heat, acting upon the thermometer, is always easily ascertained.

This philosopher found, by this method, that his thermometer, thus situated, never rose above seven and a half degrees, nor sank below six; which gave him a mean of about 1200° for the temperature of the solar rays.

It has often been asked if the rays of light, of which the velocity is excessive, have an appreciable impulsive force? Their velocity, we are able to demonstrate, is, in a right line, at a rate no less than 192,500 miles per second of time; but the most delicate experiments have not yet been able to detect, or render sensible, the least impulsive force, in these rays. The fact

has, indeed, been *assumed*, for the purpose of sustaining a *theory*, with regard to comets, as the pupil will learn in the subsequent part of this volume; but we should ever carefully distinguish between mere theory, and demonstrative facts.

## THE MOON, ☽.

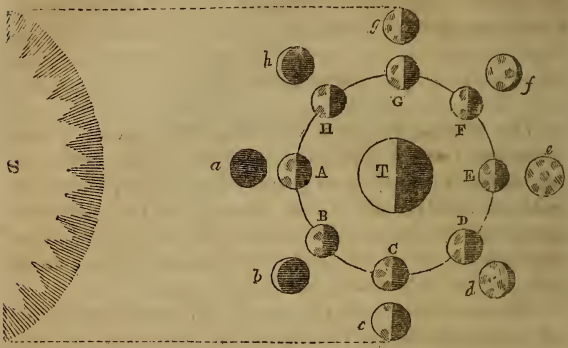
The moon, we have already seen, is, in volume, only about one fiftieth part so great as the earth, and its distance from us is about 240,000 miles; so that with an instrument which magnifies one thousand times we should see this planet the same in size and appearance, as if we were viewing it, with the naked eye, at the distance of 240 miles.

The movements of the moon are exceedingly complicated; and they were, for a long time, the source of very great embarrassment to astronomers. The moon moves in an ellipse, of which the earth occupies one of the *foci*, or focuses; and it describes this ellipse in 29 days, 12 hours, $44^m\ 2^s$. The moon is, at the same time, borne along through space, by the earth, in its movement round the sun; and while this last consumes one whole year to accomplish a single revolution in its orbit, the moon, in the same time, traverses her orbit thirteen and a half times. The moon turns upon its axis in precisely the same time that it executes its revolution round the earth; for which reason it never presents to our view any other than the same portion of its surface.

It is from the combination of its different motions, that arise the phases of the moon; in other words, the different aspects under which we see this planet, at the different periods of its course. To illustrate these, suppose, Fig. 24, S the sun, and T the earth, and we have there a view of the moon in its various phases, or appearances. When it is at A, and therefore in

conjunction with the sun, it presents to the earth the unenlightened half of its surface; and it has therefore

Fig. 24.




the appearance as shown at *a*. Arrived at B, after having run over one eighth part of its orbit, from the point of conjunction, it will present to the earth one quarter of its enlightened part, and will then appear as shown at *b*. At C it will have described one quarter of its orbit, and consequently will there exhibit to the earth one half of its illuminated surface, as seen at *c*. At D it will show more than half the illuminated portion, and will appear as at *d;* while at E the whole enlightened half becomes visible from the earth, the moon being then full, as shown at *e*. From the point E the enlightened, visible portion of the moon declines; and through the remaining half of its orbit this body presents the same phenomena as in the first half, except that they occur in an inverted order, as shown in the figure; the interiour circle of which exhibits the moon as it would appear to a spectator placed upon the sun, and the exteriour circle shows its several appearances to a spectator upon the earth.

Such are the different phases which the moon exhibits, all within the space of 29 days and a half. When it is *full*, that is, when it presents all its enlightened side to the earth, as at E, we say it is then in *opposition* with the sun; when it is new, that is, when none of its enlightened surface is visible to the earth, as at A, it is invisible to us; and we then say it is in *conjunction*. These two points are called the *syzygies*. It is there that the eclipses of the sun and moon take place, as will be shown hereafter. Finally, the moon is in its first or its last quarter, when it shows to us one half of its enlightened part; and these positions have received the name of *quadratures*, while the points intermediate between the quadratures and the syzygies are designated *octants*.

The movement of the moon is much more rapid than that of the sun. Indeed, the sun advances less than one degree each day, while the velocity of the moon is about thirteen times greater, from whence its return to the meridian is retarded $48^m\ 46^s$ each day. It is to the difference of the rapidity of these movements that is to be ascribed the return of the conjunction after 29 days and a half.

The plane of the orbit of the moon is inclined to the ecliptick by the mean quantity of $5°\ 8'\ 49''$; and the points of the intersection of these planes are called *nodes*. One of these is the *ascending* node, ☊, when the moon advances towards the north; and the other *descending*, ☋, when it recedes towards the south pole. Incontestable facts, based upon the most exact observations, prove to us that the nodes of the moon have a progressive motion towards the west, thus passing over the ecliptick in the direction contrary to the apparent movement of the sun, or in the direction of the daily motion from east to west. The node thus shifts its place westward about $19\frac{1}{3}°$ during the year, which makes about 1° for every nineteen days, or an entire

revolution of the heavens every eighteen years and a half. More exactly, the nodes retrograde 19°.3286 per year; and consequently accomplish the circuit of the ecliptick in 6788 days .54019. What is designated the *synodical revolution of the node* is a period of 346 days .61963; that is to say, after this interval of time the sun arrives again at the moon's node. As the sun moves in a direction contrary to the node, this luminary comes again to the node before it has fully completed the entire circuit of the heavens; which explains why this period is less than an entire year. The pupil has already learned that the moon executes its revolution in its orbit, and its rotation upon its axis in the same time, and that it should, therefore, and does, present to us constantly the same face. But, notwithstanding this, we perceive, by the observation of spots upon the moon, that it also shows, sometimes a little more than this, and sometimes a little less, upon one side and then the other, as if it had a slight swinging or balancing motion. This is called the moon's *libration;* a term which expresses the motion which we have mentioned, and it well describes the appearance in question, although it must not be taken literally, for this apparent oscillation is the result of an optical illusion.

Indeed, the movement of the moon, in its orbit, varies, according as it approaches the earth or elongates itself from it, while its movement of rotation is always uniform. From this it results that, during the moon's acceleration it shows, upon its eastern border, some portion of its surface, which was not before visible, while a corresponding portion, upon the west, disappears from view: and the same phenomenon, but reversed, is produced during the period of the moon's retardation. This is called the moon's *libration in longitude.*

The *libration in latitude*, arises from the fact that the moon, presenting constantly the same hemisphere towards the centre of the earth, and the observer not being placed there, but upon the earth's surface, perceives, when the moon is in the horizon, a portion more, upon one side, and a corresponding quantity less upon the other.

## PHYSICAL CONSTITUTION OF THE MOON.

The phenomena of the phases have proved to us that the moon is not, like the sun, luminous, of itself, but that it is an opaque body, which shines only by reflecting borrowed light. There is, upon the unenlightened portions of the moon's disk, a faint light perceptible, which has a slightly reddish tinge. This proceeds from the light which the earth reflects to the moon, and which must fall upon all parts of her hemisphere which is turned towards us.

When we observe the disk of the moon, with the naked eye, many irregularities are perceived upon it; the nature of which we are unable to determine. But upon aiding the view with a good telescope, we readily distinguish, soon after new moon, and upon those parts of this planet that are not then enlightened by the sun, a great number of luminous points, which continually augment, in size, in proportion as the rays of the sun come more directly upon the surface which they occupy. Upon the sides of these which are opposite to the sun, there are projected dense shadows which, as the sun changes place will be observed always to remain, as at first, upon the sides directly opposite to that luminary. These brilliant points are the summits of high mountains, which receive the rays of the sun before the less elevated portions of the surface are enlightened by it, just as the mountains of our earth do, at sunrise; and the dark portions,

clouded with shadows, are the cavities, or valleys between these mountains, which usually somewhat resemble the craters of volcanoes. Geometry has supplied us with the means of measuring the heights of these mountains. They are found to be very elevated, for a globe no larger than the moon; although they are not so high as some of the peaks of the Himaleh mountains, in Asia. The shadows which these mountains project have enabled us to measure their height, as well as the depth of the valleys. It is to the presence of these mountain peaks that is to be ascribed that irregular row of beautifully bright but detached spots, like silver points, which are sometimes seen, through the telescope, bordering the disk of the moon; that appearance being produced by the illumination of the tops of the mountains, by the sun's rays, while the valleys, between these peaks, are still in darkness, those rays not having yet attained the base of the mountains, as they do during full moon.

The moon has no atmosphere; or, at least, if it has one, it is so rare as not to differ essentially from a void, since it produces no refraction of the rays of light. This is demonstrated by the immersions of the stars. These bodies, whenever eclipsed, to us, by the moon, are invisible the exact periods of time which calculations require them to be; which could not be the case, if the moon had an atmosphere which refracted the rays of light while passing from these stars to us.

The axis of the moon being almost perpendicular to the ecliptick, the sun never sensibly departs from the moon's equator, to move north and south, at different periods of the year, as it does with us; and from this circumstance it is that the moon does not experience the variety of seasons which we enjoy upon the earth. But, as the moon turns upon its axis only once during an entire revolution round the earth, in its

orbit, each of its days and each of its nights is about fifteen times twenty-four of our hours; and what is far more singular, still, is, that one half the moon is enlightened by the reflected light from the earth, during the absence of the sun, and consequently has no absolute night, while the other half has no light whatever, save that of the stars, for periods of about fifteen of our days.

Lagrange has endeavoured to explain the cause of the moon's revolving in her orbit, and turning upon her axis, in precisely the same period of time. He supposed—and he extended this supposition to all the other satellites—that the face of the moon, which is turned towards us, is much elongated, or protruded from the centre, comparatively to the opposite part, and that this excess of matter, and of course of weight, causes the moon to remain with the same face towards the earth, in obedience to the attraction which our planet constantly exercises upon it.

To a spectator placed upon the moon the earth would appear thirteen times larger than the moon appears to us; and it would, to such observer, present regular phases, as the moon does to us, as shown, Fig. 24, page 108. These would at all times be invisible to one half the moon; while from the centre of the other half, sight of the earth would never be lost.

As the earth turns upon its axis the appearance that it would present to a spectator upon the moon would necessarily be very varied. The seas, the continents, the extensive forests, and the numerous islands would present portions of various magnitudes and of different degrees of light; while the atmosphere, with its clouds, must continually modify these several tints.

We have already seen that the sun is continually in the equator of the moon; and from this circumstance inhabitants there would not enjoy the same means that we do, of calculating time. We measure the year

by the return of the equinoxes, while their days would be always equal. They would, however, be enabled to measure by observing the poles of our earth, one of which would become enlightened and the other obscure, at each return of the equinoxes.

Philosophers have carefully endeavoured to ascertain what are the properties of the luminous rays which are reflected to us from the moon; but the most delicate experiments have wholly failed to disclose, in them, any heating, or chymical properties, whatever. On the contrary, these rays, when concentrated in the focus of the largest mirrors, produce no sensible heat. For this experiment a bent tube has been employed, the extremities of which were terminated, each by a ball, filled with air, one of which was transparent and the other blackened, the middle of the tube being occupied by a coloured liquid. In this instrument, when there is an absorption of heat, the black ball absorbs much more than the other, and the air which it contains, being thus expanded, forces the coloured liquid towards the opposite extremity. This instrument is so delicate that it readily indicates the change, in temperature, of one thousandth of a degree; and yet, in the experiments cited, it showed no change. We are justified, then, in the assertion that the light reflected to us, by the moon, has no sensible calorifick properties. That it has no chymical properties is equally well sustained. The hydro-chlorate of silver, a substance which is instantly blackened under the influence of the sun, has been exposed to its action without the least perceptible result.

But, notwithstanding these facts, credulity has attached to the light of the moon, in almost all countries, peculiar and extraordinary influences over agricultural productions. In France the field cultivators apply to the moon a particular name, during the last of April and the early part of May, as descriptive of its per-

nicious agency, at that period. It is then, say they, that the moon freezes the yet tender buds, and exercises, over all tender vegetation, a malign influence. Now, it is very easy to exculpate the moon from the charge of these misdeeds. The period of the year here fixed upon is one when, in France, where these notions prevail, the temperature is often not more than four, five or six degrees above freezing. Now it is well known that plants lose, during the night, by radiation, a portion of the heat which they have received during the day; and experiments prove that this loss amounts to seven or even eight degrees, when the nights are serene, and without clouds to counteract the effect of radiation. When clouds prevail, these radiate, in their turn, towards the earth, forming, thus, a species of screen by which the heat that is radiated from the earth is arrested, and prevented from escaping into the upper regions of the atmosphere. The temperature of the young plants, which was not more than from 4 to 5 degrees above freezing, during the day, would thus fall, during the night, by radiation, several degrees below the freezing point, and of course would become congealed. But, as this great amount of radiation could not take place except upon such nights as when the heavens were unclouded, and consequently, when the moon would be visible, effects which are only the ordinary and necessary result of the change of temperature which we have mentioned, have been ignorantly ascribed to the freezing influence of the rays of the moon. The faith in this errour has been much strengthened—perhaps, indeed, it was originated—by the success of the precautions which are often taken, by these people, against the supposed agency of the moon; but which are, in truth, precautions against the effects of radiation. The gardeners, in such cases as we have stated, to guard the tender buds and shoots from the rays of the moon,

during its supposed reign of malignity, cover them with straw, or other materials, which forms a screen, serving, like the clouds, to prevent radiation. In this way, while they save their plants, they suppose they have proved the moon's agency in their destruction.

Equally fallacious and absurd are the important agencies which agricultural and pastoral people, in almost every country, even at this late day, ascribe to the moon, in determining the seed time, and the success or failure of their various crops, and the character of the healthy or diseased condition of the young of their domestick animals, &c. All this is no other than the remains of that ancient Astrology which so long held the world in supertitious dread of its secret influences; and it can only be removed by minute and accurate acquaintance with such laws of nature as investigations have laid open to our view.

But it is not alone the present age which attributes noxious and peculiar influences to the moon. The ancients often did the same; and we have the authority of Pliny, Aristotle, and others, for saying that through the agency of the moon the bodies of oysters and other shellfish are increased and diminished; that the mass of man's blood is varied, in like manner, and by the same cause; that all animals, but particularly man, expire at the time of ebb tide; that the moon inclines us to repose, &c.; with much more, equally ridiculous and unphilosophical; and we cite this here only to show in what a catalogue of ancient, ridiculous follies our present superstitions, with regard to the moon, belong. Plutarch, too, pretends that the moon's light putrifies animal substances. Now, it is very true that if we place, in the open air, two pieces of meat, for instance, and one of these be exposed to the rays of the moon, while the other is guarded by a screen, or covering, the first of these will be much sooner attacked, by putrefaction, than the last; but here, as in

the case of the plants, men have attributed to the moon an effect which it has no agency in producing. Although the piece of meat exposed to the moon's rays will become first tainted, yet this is wholly owing to the fact that, having no shield to check the radiation of heat from it, it will become much colder, in the same period of time, than the other piece, and consequently will be more highly charged with humidity, by condensation of water from the atmosphere: and, because water is a powerful agent, in the decomposition of animal matter, we often dry meats to preserve them.

Another errour, no less ancient, nor less widely diffused among mankind, is that which attributes, to the phases of the moon, and to its passage through its phases, an influence upon atmospherick variations, and the changes of weather. This popular errour, which we find in the most ancient, no less than the most modern authors, is wholly without foundation. Aside from the fact that we can see no way in which the action of the moon could produce any such results, the most exact and careful observations, continued through long periods of time, give the most formal denial to this assumption. The changes of weather are not more frequent, at the passages of the moon from one quarter to another, than at any other epoch; indeed, if there is any difference—though no rule prevails, which is distinguishable—it would often appear to be in favour of the octants.

What, then, it may be asked, can be the cause of an errour so long and so constantly accredited? There may be several; and the general tendency of the human mind, when uninstructed, to give credence to omens, of all kinds, is probably one. This pre-conception has doubtless been strengthened by a want of impartial observations, and by the involuntary inclination of all theorists to register and remember only

such facts as seem favourable to their pre-conceived opinions, while they habitually omit all account of such as militate against them. Consequently, a change of weather happening at a new quarter of the moon, is noticed as a confirmation of the assumed theory, while twenty other changes of quarters, that are unaccompanied by any corresponding changes of weather, are not even observed. Another cause is readily found in the fact that, as the moon changes once in seven days, no change of weather can take place at a longer time than three and a half days from a change of the moon, while most of these must needs occur at much less intervals: and those who are wont to ascribe storms and other atmospherick changes to the agency of the moon, have never deemed this short lapse of time any objection to their favourite superstition. In defence of the errour here exposed, the name of Theophrastus, a Greek scholar, who lived before the christian era, has been cited; but this is an authority of but little weight in science, and particularly in a question of this sort, that has been determined by exact observations. And even the authority itself involves a contradiction. Theophrastus states that the new moon brings stormy weather, the full moon fair; and that the weather changes at each quarter. Now if, at new moon, the weather is stormy, it will be fair at the second quarter, according to this author's position: and consequently stormy, again, at the full, in contradiction with the previous part of the proposition.

A learned modern, who has written a work in defence of the popular opinions, upon this subject, has sought to support them by scientifick considerations; but he has fallen into the grossest errours, and only obtained the results he sought by including a greater or less number of days in his observations, according as he had need of more or less of atmospherick changes.

It has been often suggested, by scientifick men, that aerolites may have been projected from the moon; and among other considerations, in support of this suggestion, it has been urged that observations render it probable that volcanoes are in active operation in the moon. We may here remark that the presence, at different intervals of time, upon the obscure surface of the moon, of brilliant, shining points, and the forms of volcanick craters which almost all the valleys of the moon appear to assume, are not sufficient evidence of volcanoes in the moon to establish their existence there. It is very true, however, that, the existence of such volcanoes once admitted, stones may be ejected by them with a force sufficient to carry them beyond the distance where they would cease to gravitate to the moon. Calculations have shown that, to accomplish this, such stones need only to issue from the crater of a lunar volcano, with a velocity equal to five and a half times that of a cannon ball; and volcanoes, upon the earth, have sometimes ejected stones with a greater velocity than this. Yet we must bear in mind that the resistance of our atmosphere, and the very great attraction of the earth over that of the moon, would prevent such stones from being carried so far as not again to fall back to the earth.

We will now proceed to examine the different hypotheses by which this astonishing phenomenon, of the fall of meteorick stones, has been attempted to be explained. To do this we must first enumerate the general circumstances which observation has made known in relation to these stones; all of which must, of course, be fully explained by any hypothesis, as the condition of its admissibility.

Aerolites are ordinarily portions of a species of flaming meteor, sometimes designated globes of fire, which pass very rapidly through the air, at various heights above the earth, and in a direction nearly par-

allel with its surface. These, in some part of their flight, usually burst, or explode, and the fragments in such cases, fall to the ground. These are all composed of the same chymical properties, and very nearly in the same proportions. They all contain much silex and iron, with magnesia, sulphur, nickel, manganese, and chrome. One of these which fell near Alais, in France, contained a small quantity of carbon; but perhaps those which have fallen elsewhere have originally contained it also, and lost it, in traversing our atmosphere; for these stones experience, during their flaming course, so high a degree of heat that a great part of all the volatile principles which enter into their primitive composition must be evaporated. One important fact requires here to be mentioned, namely, that iron and nickel occur in these stones, in a metallick state, which is not the case in any of the mineral aggregations which we find upon the surface of the earth. It is certain, also, that these stones do not, naturally, pertain to the earth's surface; all which are known having fallen from the air.

Such are the facts: for the explanation of them several systems have been proposed, all which may be reduced to the three following hypotheses:

1st. That aerolites, like rain and hail, are actual meteors, which are formed, by aggregation, in the atmosphere.

2d. That they are either fragments of planets which have been shattered, or small, entire planets which, in revolving in space, have been attracted into our atmosphere, and, losing, gradually, their velocity, by the resistance of that atmosphere, have finally fallen to the earth.

3d. Laplace, the author of the Mécanique Céleste, has suggested that aerolites may owe their origin to the eruptions of lunar volcanoes, which may have ejected these stones with such force and velocity as to

carry them beyond the sphere of the moon's attraction, and thus cause them to become new satellites of the earth, but of so small a mass as to be subject to very great perturbations. If, after having circulated for an indefinite period, in the regions of space, these small bodies be finally drawn within the atmosphere of the earth, the result, as in the preceding case, would precipitate them upon the earth.

Of these three hypotheses, the first, which, without examination, appears the most simple and the most natural, is nevertheless the most improbable one of the three, and will not sustain a moment's examination.

In order that these stones might be formed, by aggregation, in the atmosphere, it is necessary that the elements of which they are composed should severally exist there. Rain and hail are, indeed, formed there, but their constituent is water, which is always present, in the air, in a state of vapour, and cold, only, is necessary to condense it into drops, or a still greater degree of cold to form it into ice, or hail. But the most exact analysis of the atmosphere has not disclosed, therein, any of the constituent principles of meteorick stones: neither sulphur, magnesia, silex, nickel or iron. Nor have we any proof that oxygen and azote, of which the atmosphere is composed, have any power to dissolve these substances. But the objection to this has been that all these experiments have been made upon portions of air taken at the surface of the earth; while there may be, in the upper regions of the air, gases capable of holding in solution those metals and earths of which aerolites are formed. But the response to this is, that the air obtained upon the highest parts of mountains to which man has been able to ascend has been submitted to analysis, and it is found to be absolutely the same, in its composition, as that at the surface of the earth. This result was easily foreseen, because it is a general law of staticks, applied to the

gases, that they extend themselves, in time, through all space which is open to them; and that, when several of these, of different natures or gravities are superimposed, the whole so combine as to form one homogeneous mass. If, then, there exists, in the upper regions of the atmosphere, any gas, capable of holding in solution the earths or metals which enter into the composition of aerolites, we should necessarily find something of it in the air at the surface of the earth; and, as we do not, the assumption that there is such gas there, is considered to be without foundation.

To this first impossibility are joined several others. Should it be admitted that the principal constituents of aerolites really exist in the atmosphere, at all heights, and that they escape detection, by analysis, because the quantity is so small, still it would be necessary to explain how it is possible for materials so scanty, and so widely diffused through the air, to be so suddenly aggregated into masses constituting stones of several hundred pounds weight, like those preserved at Ensisheim, in France; or of three or four thousand stones, of various sizes, like those which have been detached from a single meteor, in its course through the air. It is necessary, also, to assign the cause which thus unites these scattered particles, and forms them into such huge masses. This is not affinity, for the elements which compose aerolites are not combined, but simply agglomerated and retained together, in juxtaposition. And yet, if these particles had not been subject to the action of any force, they would fall to the earth, individually, as fast as formed, instead of coming down, as they do, in such ponderous masses. It is in vain to object, here, that they may be sustained more or less time in the air by some cause analogous to that which, according to the ingenious opinion of Volta, balances hailstones between the clouds, in such a manner as gives them time to augment in bulk, by

successive layers of ice; for these hailstones have never been known to reach so disproportionate a mass as several hundred pounds weight, although water, of which they are composed, is much more abundant, in the air, than, even by this hypothesis, the constituent elements of aerolites can be supposed to be. Furthermore, in the opinion of Volta, the suspension of hailstones, in the air, is attributable to the reciprocal action of electrical clouds; and this cause cannot be adapted to the facts in cases of aerolites, as they often fall at times when the heavens are wholly unclouded and serene. Finally, if aerolites were formed in the atmosphere, like rain and hail, they would, like these last, in obedience to the laws of gravity, fall in perpendicular lines to the earth; or they would deviate no more from such lines, than might arise from the influence of the winds. But this is not so; for the aerolites have, in their fall, a very rapid horizontal motion, in some instances nearly or quite equal, in velocity, to the motion of our earth in its orbit. This fact, alone, is sufficient to show the impossibility of the formation of meteorick stones in the atmosphere; if, indeed, the chymical objections which we have already cited, have not fully established this fact.

The second hypothesis which has been formed, upon the origin of these masses, is much more probable. So small planets have recently been discovered, that some degree of probability seems thus given to the existence of still smaller ones, of which our meteorick stones may have formed portions. These small planets, entering into our atmosphere, and there losing, little by little, their original velocity, would thus be brought, at last, to the earth. Before this could take place, however, the compression of the air, before the moving body, would undoubtedly be sufficient greatly to heat the stony mass; so that the combustible materials it might contain would be lighted into flame, as we see

actually take place. This hypothesis, then, fully accounts for all the circumstances attending the fall of these meteorick bodies; but it in no wise explains their identity of composition, unless we assume that all the planets so small as to belong to this class, are absolutely of the same nature and composition; of the same elements, in the same proportions; which assuption is not warranted by any thing we know upon the earth; and which, applied to the other bodies of our solar system, is exceedingly improbable. There is, also, in this hypothesis, something at open war with all we know, and all that we have reason to believe, in nature; for it involves a degree of imperfection in the mechanism of the Universe, which implies its destruction by age, unless that catastrophe shall be prevented by occasional repairs!

But the identity of the chymical composition of these aerolites finds its ready explanation in the third hypothesis, namely, that which supposes these stones the product of lunar volcanoes; for then it is sufficient to suppose, either that all these volcanoes emit only such substances; or that the stones are the production of one or more particular ones, which alone eject their contents with sufficient force to throw them beyond the sphere of the moon's attraction. That degree of force, as calculation has shown, is not very great, because the moon is not surrounded by an atmosphere which would resist their flight. But, as we have before observed, if the existence of lunar volcanoes is rendered probable, by astronomical observations, it is by no means demonstrated. Yet if the existence of these volcanoes be once admitted, the explanation of the phenomena then becomes one strictly mechanical. It is easy to conceive, between the earth and the moon, a line which marks that division in space where the attraction of the earth and that of the moon is equal. This, of course is much nearer the moon than the

earth, because the mass of the moon is so much less than that of the earth. When the meteorick stones, issuing from the lunar volcano, have once passed this line, which may take place in a variety of directions, they must instantly become satellites of the earth; but they would be satellites which would experience enormous disturbances, by reason of the smallness of their masses, relatively to those of the earth, the moon and the sun, by all of which they must be powerfully attracted. When, by reason of these disturbances, one of these stones shall have been brought within the atmosphere of the earth, the resistance of that atmosphere would lessen its velocity more and more, until, as in the preceding case, the body would finally fall to the earth.

We have thus submitted the facts which support the hypothesis of aerolites' emanating from the moon, and which seem to render that the most probable of any yet suggested; since it is the only one which satisfactorily accounts for all the phenomena coupled with this interesting subject. But we must not forget that, as we have before stated, the existence of volcanoes in the moon is by no means established; nor should we overlook, here, the fact that the transfer of matter from one planet to another, which this hypothesis involves, is, no less than the preceding, obnoxious to the charge of involving, also, that imperfection of the mechanism of the universe to which we have before alluded.

# CHAPTER SIXTH.

## INFERIOUR PLANETS.

### MERCURY, ☿.

Mercury is the nearest planet to the sun. It is visible, at night, after the setting of the sun, in the western part of the heavens, under the form of a small, but very brilliant disk, which, at first, difficult to distinguish, by reason of the twilight, becomes more and more visible, in proportion as the planet's distance from the sun increases, until, reaching its utmost distance from that luminary, it becomes, for sometime apparently stationary. This first part of its course is *direct*, like that of all the planets. It soon, however, again approximates the sun, and finally becomes lost in its rays. Soon after this disappearance in the *west*, it reappears in the *east*, rising before the sun. Here, of course, it is on the opposite side of the sun, from its position when seen in the west; and, as before, it gradually increases its distance from the sun, until, reaching its utmost limit, it first becomes stationary, in appearance, and then slowly plunges itself again into the rays of the sun, and disappears—again to present itself in the west, as before.

The short duration of the appearance of Mercury arises from its vicinity to the sun, from which its angular distance is never more than about 29°, nor less than about 16°. The mean distance of Mercury, from the sun, is about 37,000,000 of miles. Its apparent diameter is about 7″, and its real diameter is very nearly two fifths of that of the earth, or about 3,200 miles. It turns upon its axis in $24^h\ 5^m\ 3^s$; while it occupies $87^d\ 23^h\ 14^m\ 30^s$ in accomplishing a revolution in its orbit. This orbit, which is wholly enclosed within that of the earth, is in the form of a very ec-

centrick ellipse, and greatly inclined to the plane of the equator of Mercury; and making, with the plane of the ecliptick, an angle of about 7°.

While Mercury is wholly immersed in the rays of the sun, it is sometimes seen passing across the disk of the sun, where it has the appearance of a small, round, black spot. This is known to be Mercury, because the position, the diameter and the motion are all those which belong to that planet. This passage across the sun is called the transit of Mercury. This does not take place at every revolution, by reason of the inclination of Mercury's orbit to the plane of the ecliptick; and we can therefore only see this planet upon the disk of the sun when it is at its point of intersection with the ecliptick, and when a line joining the centres of the sun and Mercury would, if prolonged, pass through the centre of the earth. The small size of this planet, its distance from the earth, and its close proximity to the sun, often prevent us from witnessing these transits, which take place, regularly, at periods of 6, 7, 13, 46 and 263 years.

### PHYSICAL CONSTITUTION OF MERCURY.

Mercury is perfectly spherical, in its form; and, like all the planets, it borrows its light from the sun. This is fully proved by its passages across the sun's disk, when, having no rays of the sun falling upon the hemisphere which it presents to us, its appearance, as stated above, is that of a black spot. The same is also proved by the observation of the phases which Mercury presents, and which, with the assistance of the telescope, we are enabled to follow, through all their changes, like those of our moon.

The employment of this instrument has also shown us that one of the extremities of the crescent of Mercury is truncated, or apparently cut off; and it is this

circumstance which has furnished astronomers the means of determining the period of this planet's rotation upon its axis; for its disk is not, like the moon, for instance, furnished with fixed spots, easily recognised. The appearance in question is an effect of the asperities with which the surface of the planet is doubtless more or less covered, and which mask from us, in a particular position, some of that portion enlightened by the sun.

We know that Mercury is enveloped by an extremely dense atmosphere. Its motion in its orbit, through space, is more rapid than that of the other planets, because it is nearer the sun. The sun, if viewed from Mercury, would appear three times greater than it does to us; and Newton has calculated that this body emits to Mercury an amount of heat seven times greater than that experienced within the torrid zone of the earth. But we are not warranted in concluding that this planet really experiences so elevated a temperature; for we are not yet sufficiently instructed in the producing causes of heat to justify us in doing so; since it may very well be that the action of luminous rays is modified by the nature of the constituent elements of the different planets.

### VENUS, ♀.

Venus is the most beautiful of the planets; which explains why it has received the name it bears. Like mercury, Venus shows itself sometimes in the morning and sometimes at evening; and it is called the morning or evening star, according as it is visible before the rising or after the setting of the sun. Some days after its conjunction with the sun, Venus is seen, at first, in the morning, west of the sun—and of course rising before it—in the form of a beautiful crescent, of which the convexity is turned towards the sun.

It is then moving west, among the stars, and as it advances its velocity decreases, while its crescent continually augments in size, until the planet reaches its greatest angular distance, and becomes stationary, when the crescent forms a half circle. From this point the planet returns eastward towards the sun, with a gradually increasing velocity, until it is lost in the solar rays. After this it is next seen at evening, east of the sun. Its form, then, is entirely round, and its apparent size is greatly diminished. Its motion, then, is to the east; while its diameter constantly increases, and its form gradually changes from round to the crescent, until the planet has reached its greatest eastern limit, when its appearance has again become that of a half circle. From this position it again withdraws towards the west, gradually approaching the sun, until it is once more lost in its beams.

The distance of Venus from the earth, like that of mercury, is very variable; as is evident, in the case of both planets, by the apparent variations of their diameters. The mean distance of Venus from the sun is 68,000,000 of miles; and its apparent diameter is very variable. This planet accomplishes its rotation upon its axis in $23^h\ 21^m\ 19^s$; and its revolution in its orbit, in $224^d\ 16^h\ 41^m$. Its orbit is inclined $3°\ 24'$ to the plane of the ecliptick, and is, like that of mercury, always enclosed within that of the earth. Venus, like mercury, sometimes passes across the sun's disk, and like that planet, Venus is seen there as a black spot. The phenomenon of these passages, in the case of Venus, is very rare, yet astronomers have profited by their occurrence to measure the sun's distance with accuracy. The pupil has already seen that in this way the parallax of the sun has been determined to about one tenth of a second.

## PHYSICAL CONSTITUTION OF VENUS.

When this planet is seen crossing the disk of the sun, it appears, like mercury, as a small round, black spot. We know, then, that its figure is spherical, and that its light is borrowed from the sun—which, indeed, we were authorized to infer from the appearances of its phases. The duration of the revolution of Venus upon its axis, like that of mercury, is determined by the asperities which this planet bears upon its surface, and which, intercepting the reflected light, give a truncated appearance to the extremities of the crescent. By carefully noting the time which elapses between any two successive returns of this appearance, the time of revolution of the planet is disclosed. Venus is enveloped in an atmosphere. This fact was determined by a German astronomer, through the assistance of the laws of opticks; and he proved that the enlightened portion of the planet is greater than it could be, without the aid of the refraction which this atmosphere produces.

Although very nearly as large as the earth, Venus moves with more rapidity, in its orbit, because it is much nearer the sun. From Venus the sun would appear almost twice as large as it does to us; and mercury is to Venus, morning and evening star, as Venus is to the earth.

The axis of Venus is inclined to the plane of its orbit 75°; or 51½° more than the axis of the earth to the ecliptick. The axis of Venus is so inclined that the northern regions of that planet have summer in the same signs of the zodiack in which we experience our winter; while our summer signs are those of winter to Venus. As the greatest declination of the sun, upon either side of the equator of Venus, is 75°, its tropicks, of course, are within 15° of its poles; and consequently its polar circles are this distance from

its equator. This planet has, then, two summers and two winters in each of its annual revolutions.

Careful and multiplied observations have been made, by astronomers, to determine if either mercury or Venus has any satellites; but none have been discovered; and these accompaniments appear to pertain only to some of the superiour planets, and to the earth.

## SUPERIOUR PLANETS.

The two planets of which we have just treated are called *inferiour planets*, because they are, as we have already seen, less removed from the sun than is the earth; while those which are now to occupy our attention have been named *superiour planets*, from the fact that their orbits are outside that of the earth; in other words, that these planets are all more distant from the sun than the one upon which we reside.

### MARS, ♂.

This planet comes next to our earth, in the order of distances from the sun. It appears to move among the stars, from west to east, round the earth; but its motion is subject to many irregularities. When first visible, in the east, before the sun, in the morning, its motion from that planet is very rapid: this, however, is gradually diminished, and finally wholly ceases, at 137°. The planet next resumes a direct motion, which carries it into opposition with the sun. Its rapidity again diminishes, gradually, and it seems to retrograde until it appears to have passed the sun 137°. Then the motion again becomes direct, and the planet is again lost in the rays of the sun.

The mean distance of Mars from the sun is 142,000,000 of miles. As its distance from the earth is very variable, this variation is manifested by the

apparent dimension of its diameter, which constantly changes with the change of distance. Careful observation of the spots which its disk presents has taught us that Mars turns upon its axis in $24^h\ 39^m\ 22^s$. It moves in a very eccentrick ellipse, in which it accomplishes its revolution in $686^d\ 23^h\ 30^m\ 42^s.4$. Its axis is inclined 61° 33′ to its orbit; and the inclination of its orbit to the ecliptick is 1° 51′ 1″. The planet's equatorial diameter is, to its polar diameter, in the proportion of 16 to 15.

Mars experiences, in its revolution in its orbit, great variations of distance from the sun: sometimes appearing near that body, and at others far from it: sometimes it rises while the sun is setting, and sometimes it sets at sunrise. Its distance from the earth, also, varies greatly; but most in its conjunctions, and least in its oppositions. Like mercury and venus, Mars presents the phenomena of phases; but the truncated appearance of the crescents of these two planets is not distinguishable in Mars.

### PHYSICAL CONSTITUTION OF MARS.

Viewed through a telescope this planet presents a round disk; and its surface exhibits great diversity of light and shade. Its phases prove to us that this planet shines by means of borrowed light, which is furnished by the sun. Spots have been identified upon the surface of Mars, by which the duration of its revolution upon its axis has been determined. The light which Mars reflects to us is of a dark red colour; which appearance is attributed to the atmosphere by which the planet is surrounded, and which is so high and so dense that when the planet passes nearly in a line between the earth and a fixed star, such star has been observed to change colour, become dim, and sometimes wholly to disappear, although at a considerable distance from the body of the planet.

Aside from the spots which have served to determine the rotary motion of Mars, several astronomers have remarked that a segment of its globe, towards the south pole, has a light so superiour to that of the rest of the disk, that it appears like a portion of some other globe, more strongly illuminated. Maraldi informs us that this brilliant spot had been observed for sixty years, and that it is the most permanent of all those upon Mars. Parts of this planet, as before stated, are more brilliant than the rest; while the darker portions are subject to great changes, and sometimes disappear. A similar light to that we have mentioned at the south pole, has often been observed, also, at the north pole. These observations were confirmed by Herschel, the elder. According to this astronomer the analogy between Mars and the earth is by far the greatest in the whole solar system. Their diurnal motion is nearly the same; the obliquity of their respective eclipticks, on which the seasons depend, not very different; while, of all the superiour planets, the distance of Mars from the sun is, of course, far the nearest to that of the earth: nor will the length of its year appear very different from ours, when compared to the surprising duration of the years of jupiter, saturn, or uranus. If, then, we find that the globe which we inhabit has its polar regions frozen, and covered with mountains of ice and snow, that only partly melt when alternately exposed to the sun, we may well be permitted to surmise that the same causes may probably have the same effects on the globe of Mars; that the bright polar spots are owing to the vivid reflection of light from its frozen regions; and that the reduction of those spots is to be ascribed to their being exposed to the sun. The spot at the south pole was extremely large in 1781, as, upon this hypothesis, it should have been, because that pole had then but recently emerged from a night of twelve

months, during all which time it was deprived of the heat of the sun; but in 1783 it was considerably smaller than before, and it continually decreased from the 20th of May to the middle of September, when its size became stationary. During this last period, the south pole had already been more than eight months enjoying the benefit of summer, and it still continued to receive the sun's rays; though towards the close of the period these fell in so oblique a direction as to impart but little heat to the surface. On the other hand, in 1781, the north polar spot, which had then been its twelve months in the beams of the sun, and was but just returning into darkness, appeared small, though doubtless it was increasing in magnitude. Its not being visible in 1783 was owing to the position of the axis, by which it was removed out of sight.

There is another consideration which strongly confirms the hypothesis that the brilliant spots about the poles of Mars are produced by the presence of snow and ice, which is, that the axis of this planet being inclined to its orbit 61° 33′, the variations of the seasons cannot be very great; and this constancy of each parallel of latitude in preserving nearly the same temperature is regarded as favourable to the formation of ice.

The sun dispenses, to Mars, only about one third as much light as is enjoyed by the earth; and yet it has no satellite, or moon. Perhaps this circumstance may be compensated for by the height and density of its atmosphere, which we have seen to be very considerable.

## OF THE FOUR TELESCOPICK PLANETS.

These planets, which are placed, in the arrangement of the solar system, between mars and jupiter, were all discovered within the present century. This

circumstance, coupled with their small size, and great distance from us, accounts for the fact that they are very little known.

### JUNO, ⚵.

This planet was discovered by Professor Harding, of Gottingen, on the first of September, 1803; and it has, according to Schrœter, a diameter of 1,138 miles. It employs 4 years and 128 days to accomplish its revolution round the sun, in an orbit inclined to the ecliptick 13°.05. Its distance from the sun is about 256,000,000 of miles.

### CERES, ⚳.

Of the four telescopick planets, Ceres was the first discovered. The discovery was made by Piazza, at Palermo, on the first day of January, 1801. Its diameter has been stated at 140 miles, by some, while others have fixed it as high as between eleven and twelve hundred miles. It is manifestly not known. It makes its revolution round the sun in 4 years 220 days, moving in an orbit of which the plane makes an angle of 10° 37′ 25″ with the ecliptick. Its distance from the sun is about 264,000,000 of miles. The appearance of this planet is that of a nebulous star, or one surrounded by a kind of haze, continually changing in its appearance, which has led Herschel to suppose the planet to possess an atmosphere.

### PALLAS, ⚴.

This member of our solar system was discovered by Dr. Olbers, of Bremen, on the 28th of March, 1802. Herschel gave to this planet a diameter of about 134 miles, while Schrœter fixed it at 14 times

this sum—sufficient evidence that nothing is known upon the subject. Its orbit, extremely elongated, has a greater inclination to the ecliptick than that of any other belonging to the solar system, being no less than 34° 37′ 30″. It revolves in its orbit round the sun in the period of 4 years, 7 months and 11 days; at the distance of about 268,000,000 of miles from that body. Pallas has a whitish colour, and is never very distinct, even when viewed with powerful telescopes.

### VESTA, ⚶.

Vesta was discovered by one of the scholars of Dr. Olbers, on the 29th of March, 1807. It describes, in three years, 66 days and 4 hours, its orbit, which appears very irregular, and which is inclined 7° 8′ 9″ to the ecliptick. This small planet is but very imperfectly known. Very powerful telescopes have been applied to it, without disclosing any disk; for it appeared, in them, like a brilliant point. Its distance from the sun is conjectured to be about 225,000,000 of miles.

Although our knowledge respecting these four planets is very imperfect, we are nevertheless enabled to state that they are extremely small, relatively to those which are near them, and to their great distance from the sun. Another anomaly which they present is, that they deviate much from the zodiack, the common highway of the other planets. From these circumstances the opinion has been ventured that these four small planets are no other than the fragments of one much larger which, revolving between mars and jupiter, by some internal convulsion, has been mechanically broken into four parts. This opinion has been supposed to derive farther support from the fact that appearances have favoured the opinion that these planets are not round; and also, from the circumstance

that their orbits are interlaced in such a manner as to cause all these planets to return to one and the same point during their revolutions; a fact which the laws of mechanicks show would be necessary to them, in the hypothesis in question: for, according to these laws, if a revolving planet were rent into two or more pieces, by internal violence, each fragment, after having described a new orbit, must return to the point where the disrupture took place. But, although these facts yield support, indeed, to the theory in question, yet they by no means confirm it: on the contrary it is so at variance with all we know in nature, that the strongest confirmation is requisite to secure to so singular a position that credence which belongs to scientifick truth.

The small size of these planets induced Herschel to deny to them the name of *planets*, and he therefore proposed to bestow upon them that of *Asteroids*. This was deemed an improper distinction, since these planets are not smaller, in comparison with mercury, than mercury is, in comparison with jupiter; and astronomers, therefore, when they have occasion to refer to these bodies, collectively, reject this name, and designate them *telescopick planets*, in reference to the difficulty of getting sight of them, as well from their small size, as, also, from their great distance.

## CHAPTER SEVENTH.

### JUPITER, ♃, AND ITS SATELLITES.

Jupiter is the largest of the planets; and, with the exception of venus, is the most brilliant. This body is 1470 times larger than our earth, and it is only by reason of its vast distance from us that it appears so small to us, in the heavens. Its revolution upon its

axis is extremely rapid, and is completed in $9^h\ 56^m\ 37^s$. Its revolution round the sun, at the mean distance of 485,000,000 of miles from that luminary, is executed in $4332^d.596$, in an ellipse of which the plane is inclined to that of the ecliptick $1°\ 46'$. The great distance at which this planet is placed prevents our distinguishing its phases, which it doubtless exhibits, like all the other planets.

When examined with a telescope, Jupiter is found to be attended by four small, luminous bodies, which move in regular orbits round it, as our moon does round the earth: these are called Jupiter's satellites. They are distinguished by their positions, and by numbers, the first being that one which is nearest to the planet. They revolve in orbits which are very nearly in the plane of the equator,

| | | | | | | |
|---|---|---|---|---|---|---|
| The | 1st. | in | $1^d$ | $18^h$ | $27^m$ | $35^s$. |
| " | 2d. | " | 3 | 13 | 13 | 42. |
| " | 3d. | " | 7 | 3 | 42 | 33. |
| " | 4th. | " | 16 | 16 | 32 | 8. |

The first three move almost in the same plane, but the fourth deviates something more. Their orbits are very nearly circular; no eccentricity has been observed, except in those of the third and the fourth, and of these it is the greatest in the last.

Herschel, in attentively examining these satellites, with a telescope, discovered that the intensity of their light experienced periodick variations, and in calculating the epochs at which their faces are turned towards us, he was enabled to determine the duration of their revolution upon their axes. He found that they always present the same face towards Jupiter; and consequently they run through their orbits, and revolve upon their axes in the same time, as we have already seen is the case with our moon. Maraldi had previously proved this true of the fourth satellite, by

noting the returns of a spot which he had observed upon its surface.

When the satellites of Jupiter, by reason of their motion in their orbits, come to be situated between the sun and Jupiter, they project, upon the enlightened part of that planet's disk a shadow, which varies in size, according to the distance and magnitude of the satellite producing it. This constitutes a partial eclipse of Jupiter; and from the fact here stated we learn, with certainty, that neither Jupiter nor its satellites are self luminous, but only shine by means of reflecting the light of the sun.

When, on the contrary, the motion of these satellites carries them to the opposite parts of their orbits, and of course *behind* the planet, relatively to us, we see them, then, successively disappear, or in other words, become eclipsed by their primary planet. The first three are eclipsed at every revolution; but the fourth moves in an orbit so much inclined that, in its oppositions to Jupiter, it is two years in six without falling into its shadow. By the singular relations which exist among the motions of the first three of these satellites, but which cannot be clearly explained here, it follows that these three satellites cannot be eclipsed at the same time; for, during the simultaneous eclipse of the second and third, the first is constantly in conjunction with Jupiter; and reciprocally.

It has always been observed that these eclipses never take place from east to west, but always upon their return from west to east: from which we learn that these satellites, like most of the planets of our system, move round their primary from west to east.

These eclipses of the satellites of Jupiter, have furnished the means, as we shall see hereafter, of determining the velocity of light: and we shall also learn that they are of great utility to mariners, in determining longitude.

## PHYSICAL CONSTITUTION OF JUPITER.

We have seen that both Jupiter and its satellites borrow their light from the sun. Although this planet is 1470 times more voluminous than the earth, its density is only one quarter as great as that of our planet. Its figure is that of a spheroid, flattened at the poles. This ellipticity, which is $\frac{1}{14}$, is an effect of the rapidity of that planet's rotary motion, as we shall demonstrate in speaking of the earth. Its axis being nearly perpendicular to the plane of its orbit, the sun is almost always in the plane of its equator: consequently the variations of the seasons are scarcely perceptible, and the days and nights are very nearly of equal length, during the entire year.

The sun, viewed from Jupiter, would appear five times less than if seen from the earth; and the heat and light which it sends to that planet are five times less than we enjoy. But its nights are very short, and enlightened by four brilliant moons, of which one, at least, is always shining.

When we examine Jupiter, with a good telescope, we perceive a number of zones, or bands, of a darker colour than the rest of its disk. They are generally parallel to the equator; but in other respects they are subject to great variations. Sometimes only a single one of these is to be seen, while at others no less than eight are visible. Frequently these are not parallel, one to another; and often, also, they are of variable lengths. Sometimes they are seen to extend, and sometimes to contract their dimensions. The time of their duration, also, varies much. Some of these bands have been seen to endure for three months, without change of form or size: while others have been formed, or have vanished in the space of one or two hours. At times the continuity of these bands is interrupted, giv-

Fig. 25.

ing them the appearance of having been broken off, and displaced. The spots and the bands which were observed upon Jupiter's disk on the 7th of April, 1792, are represented in fig. 25. These bands are supposed to be portions of the body of the planet; and the luminous parts to be clouds transported by winds, often with great velocity, and in different directions.

## SATURN, ♄, ITS RINGS AND ITS SATELLITES.

Viewed with the naked eye Saturn presents to us the appearance of a nebulous star, of a dull, leaden colour; and as its motion is very slow, it is often, by others than astronomers, confounded with the fixed stars. It presents, parallel to its equator, a series of bands, analogous to those of jupiter, although not as dark and distinct; and it was by the aid of these that Herschel determined its movement of rotation upon its axis, which is accomplished in $10^h\ 29^m\ 2^s$. It moves, at the distance of about 890,000,000 of miles from the sun, in an orbit in which it describes its revolution round the sun in twenty-nine years, five months and fourteen days, and of which the inclination to the ecliptick is $2°\ 27'$. This planet is nearly nine hundred times larger than the earth; and the sun dispenses to it only about one eighth part of the light which the earth receives.

Like jupiter, Saturn has satellites, but in greater number. It has seven—six of which move very nearly in the plane of the equator, but the seventh deviates very sensibly from this path; the inclination of its orbit being about 30°. Observation has shown that this

satellite, like our moon, turns upon its axis in the same time that it completes a revolution in its orbit; so that it always presents the same part of its surface to its primary planet. We have not, indeed, been able to determine that this is true of the remaining satellites of Saturn, but analogy strongly induces to the belief that it is; for this equality of duration of the movements of translation and of revolution appears to be a law of the secondary planets.

The duration of the revolution of the different satellites of Saturn is very unequal, as will be seen by the following table, in which their mean siderial revolutions are given, and their mean distances from their primary are expressed in the radii of that planet—its diameter being 79,000 miles.

| No. of Satellite. | Siderial period. | Distance from primary. |
|---|---|---|
| 1st. | $22^h\ 37^m\ 23^s$; | 3 .351. |
| 2d. | $1^d\ 8\ 53\ 9$; | 4 .300. |
| 3d. | $1\ 21\ 18\ 26$; | 5 .284. |
| 4th. | $2\ 17\ 44\ 51$, | 6 .819. |
| 5th. | $4\ 12\ 25\ 11$; | 9 .524. |
| 6th. | $15\ 22\ 41\ 14$; | 22 .081. |
| 7th. | $79\ 7\ 54\ 37$; | 64 .359. |

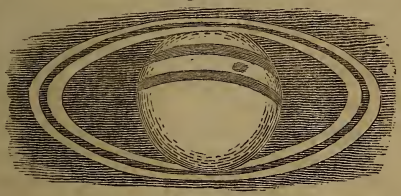
The satellites of Saturn experience frequent eclipses, and these, like those of jupiter, serve for the determination of longitude; but their great distance renders observations upon them both difficult and uncertain.

A law, which is that of Bode's, already noticed, has recently been determined to exist among the satellites of Saturn. The distances of these from their primary may be expressed by the following numbers; 1, 2, 4, 8, 16, —, 64. There seems to exist a void, according

to Bode's law, between the sixth and seventh of these satellites, which leaves room to suspect that another body, yet undiscovered, revolves there. Such a void was long supposed to exist between the orbits, of mars and jupiter, which was filled, at the beginning of the present century, by the discovery of the telescopick planets, which satisfied the law in question. See pages 100 and 101.

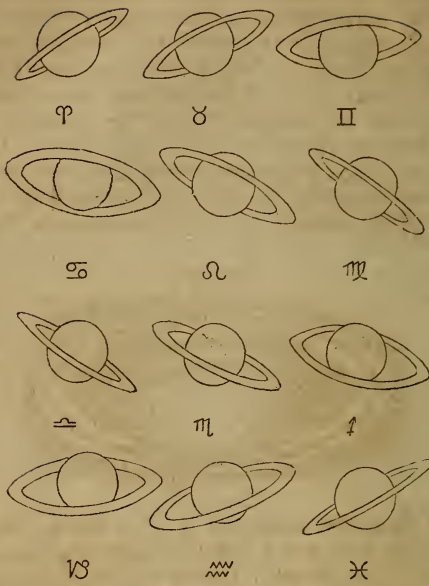
Saturn, which is already so remarkable for the number of its satellites, is rendered still more so by the rings which envelop it; as represented in fig. 26.

Fig. 26.



These rings are concentrick; very broad, and thin; both lying in the same plane, and that the plane of the equator of the planet. To this body they constitute a kind of zone, or band, although separated from the surface of the planet by a space of many thousands of miles, upon every side. Viewed from the earth these rings present themselves under an elliptical form, more or less elongated, according to the obliquity under which they are seen; and which arises from the different degrees of inclination which the planet Saturn assumes, with regard to the earth, while traversing its orbit. The following sketches, twelve in number, fig. 27, illustrate the different appearances of this planet and its rings, in the several constellations.

Fig. 27.




By these figures it will be seen that the rings are never so situated with regard to the earth as that the plane of them should lie at right angles to our line of vision; but that we always view their sides under a greater or less degree of obliquity. Were they placed with the side fully presented to our sight, they would then be deprived of that elliptical appearance which now distinguishes them, and assume a circular form. There are several of the positions shown in the figures, as that in ♊, and in ♋, where stars may be seen between the planet and the inner ring; while in ♈, ♎, &c. the obliquity is so great as to prevent this. As

some of these figures exhibit one side of the rings to view, and some the other, it follows that there must be times when neither side is visible. This occurs when their position is such as that the prolongation of their plane passes through the centre of the earth. At such a time the edge of the outer ring, only, is presented to us; and this is so thin, (about one hundred miles,) and the angle which it subtends is so small that telescopes of very great light and high magnifying power are necessary to render it visible. When thus seen, it resembles a luminous line or thread, crossing the disk of the planet. This phenomenon occurs once in every fifteen years.

By employing very powerful telescopes we discover, upon the surface of Saturn's ring, several concentrick, black lines, appearing like divisions; and one of these was clearly determined to be such, by Herschel, who calculated its dimensions, and thus established the existence of two distinct rings. According to this astronomer the following dimensions exist:

| | | |
|---|---|---|
| Interval between the planet and the inner ring, | 19,090 | miles. |
| Inner diameter of the inner ring, | 117,339 | " |
| Outer diameter of the same, | 151,690 | " |
| Inner diameter of the outer ring, | 155,272 | " |
| Outer diameter of the same, | 176,418 | " |
| Interval between the two rings, | 1,791 | " |
| Thickness of the rings, | 100 | " |

By means of spots of unequal brightness, upon the rings, Herschel determined the duration of their revolution upon their axis to be $10^h\ 29^m\ 16^s$; which differs but little, and probably no more than the unavoidable errour of observation, from the time assigned them by Laplace, as deduced from the laws of gravity. Their axis of rotation is perpendicular to their plane, and is the same as that of Saturn.

The duration of this rotation, which appears to be precisely that of a satellite which should have for its orbit the mean circumference of the ring, has furnished Mons. Biot with data wherewith to explain how the rings of Saturn are sustained in their position around that planet, without touching it; or rather, with the means of connecting this fact with the general cause which equally sustains all satellites.

This he does by showing that each particle of which the rings are composed may be considered a small but distinct satellite of Saturn; and the rings themselves, therefore, are no other than a mass of satellites, united together in an unchangeable manner. If these particles were all detached from each other, their velocity would vary with their distance from the centre of the primary planet, those nearest to this point moving with the greatest, and those most remote, with the least velocity: and if we take, for the mean term, the velocity which pertains to the mean circumference of the ring, the velocity of the other particles would differ from this (some more and some less) by an equal quantity. Now, if all these particles be united, and attached, so as to form a solid body, a kind of compensation in their several movements would be the result; the most rapid would communicate to those moving more slowly a portion of their velocity, at the same time that the slower would assist in retarding these; the opposite forces thus tending to produce an equilibrium, until the whole would result in a mean movement, common to all the particles, which would be that of the mean circumference. These rings, then, are sustained in their place, around Saturn, just as the moon is sustained in its place round the earth.

This theory still holds good, if we suppose Saturn's appendage to be composed, as we shall soon see it really is, of several concentrick rings, separate and detached from each other; only, in that case, it would

be necessary to apply it separately to each of them, because the duration of their rotation would be sensibly different.

Sometimes the rings of Saturn are projected upon the disk of the planet, so as to hide a portion of it from our sight, and at others the planet so intervenes as in like manner to eclipse a portion of the rings. Examples of both these results will be seen in the diagrams, fig. 27, page 144. From this it follows that both the planet and its rings are solid, opaque bodies, borrowing their light from the sun.

The rings, though very nearly concentrick with the planet, are not strictly so; their centre of gravity being found to describe, around the centre of gravity of the planet, a very minute orbit. This fact, it has been demonstrated, is indispensable to the stability of the rings; and but for that, they would be thrown down upon the planet, so that, upon some side their inner edge would come in contact with its surface, where it would then inevitably remain. It is worthy of remark, also, that in the progress of Saturn in its orbit, as the rings go with it, each of these rings and the planet itself must needs have exactly the same projectile velocity, since the slightest difference would speedily derange and destroy the whole adjustment.

The foregoing embraces all that astronomers knew of Saturn and its appendages, prior to the year 1838. Several astronomers had previously *suspected* the rings of Saturn to be more than two in number; but with the telescopes they employed it was impossible to decide. Laplace, as early as 1787, supposed the ring of Saturn might have many divisions; while Herschel contended that no observations would justify this supposition. But a new telescope, more powerful and perfect than any previous one, now in use at Rome, in Italy, appears to have set this point at rest. This telescope was made by *Cauchoix;* and with it, on the night of

the 29th of May, 1838, the astronomers of the Roman College, at Rome, first suspected they had new proof of additional divisions in the rings of Saturn. Their observations were continued; and the evidence becoming stronger, they invited Mons. *Decuppis* to assist in pursuing the subject. From the published result of these investigations there appears no doubt that the rings of Saturn are six in number, instead of two, as Herschel supposed them. The figure in front of the titlepage has been prepared from the description given of these discoveries; and it is drawn with the plane of the rings at right angles to the line of vision, because the different proportions are much more perfectly shown, and will be better understood in this way; although the earth never occupies a position which commands such a view of Saturn and its rings, in the heavens. In this diagram the white portions, or bands, surrounding the planet, represent Saturn's rings, while the dark ones, some of which appear only as lines, denote the spaces between the rings, and between the inner ring and the body of the planet.

The following are the results of these discoveries, as published by the French Academy of Sciences, in a tabular form.

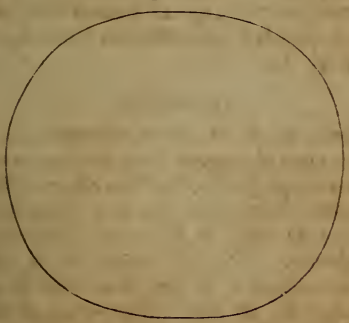
TABLE OF THE APPROXIMATE DIMENSIONS OF SATURN AND ITS RINGS.

| | Miles. |
|---|---|
| Equatorial diameter of the planet, | 79,000 |
| Interval between Saturn and the interiour ring, | 18,478 |
| Internal diameter of the interiour ring, | 117,311 |
| Diameter of the first division, | 125,539 |
| Diameter of the second division, | 137,412 |
| Diameter of the third division, | 145,611? |
| External diameter of the interiour ring, | 153,547 |
| Interval between the two rings, | 1,914? |
| Internal diameter of the exteriour ring, | 155,233 |
| Diameter of the fourth division, | 166,453 |
| External diameter of the exteriour ring, | 176,376 |

In this table the two rings, as previously known, and the interval between them, are constantly spoken of, while the new partitions are laid down as divisions of those rings. The space between the planet and the inner ring, and also that between the two rings, as previously known, are laid down in their due proportions; but the rest of the divisions between the several rings, as we have no means of ascertaining their width, are shown only by lines.

In 1805 Sir William Herschel believed he had detected a peculiarity in the figure of Saturn, which he subsequently proved, by his method of calculations. The result of his observations and calculations was, that the greatest diameter of this planet is not at the equator, as in the other planets, but through the latitude 43° 20′: and this deviation from the form of the other planets he supposed to arise from the attraction of the ring. The results thus obtained Herschel published, in the Philosophical Transactions of the Royal

Fig. 28.



Society, in 1806, where he illustrated his theory by a drawing of the planet; and which we have copied here, figure 28.

The name of Herschel is of so great weight, in astronomy, that this supposed discovery of his has been promptly adopted, in this country, to some extent, at least; and has found its way into text books, of high standing, whose authors unfortunately had not met with its entire refutation. Such refutation, however, was furnished in 1832, by Mons. Bessel, in a determination of the dimensions and position of the rings of Saturn, and the dimensions and form of that planet. With particular reference to Herschel's publication upon this subject, and with instruments far more perfect than those possessed by Herschel, Bessel carefully measured the diameter of this planet, at the equator, and at latitudes 22° 30′, 45°, 67° 30′, and 90°. From these measures it is established that the greatest diameter of Saturn is through its equator, and its least is through its poles—as is the case with all the other planets, so far as known. The agency of the rings of Saturn, too, in producing the shape Herschel supposed that planet to have, is equally disproved by theory, as by admeasurement. The result, then, both of direct measurement, and of calculations, says Mons. Bessel, is in positive contradiction to the figure of Saturn, given by Herschel.

### URANUS, ♅.

This planet is, of all those belonging to the solar system, the most elongated from the sun, and its orbit therefore envelops those of all the others. Situated at 1,800,000,000 miles from the sun it accomplishes its revolution in its orbit in 84 years, 29 days, 8 hours and 39 minutes. The inclination of its orbit to the plane of the ecliptick is less than that of any other planet, being only 46′ 26″. The period of the diurnal rotation of this planet has not been determined.

To the naked eye Uranus is barely visible: in the telescope its disk is well defined, and appears of a blu-

ish white colour. Owing to the great distance at which this planet is placed from the centre of the solar system, it receives only the three hundred and sixty-second part of the light from the sun which that body emits to the planet we inhabit.

Although often seen, and several times entered in catalogues of fixed stars, as one of their number, yet Uranus was never supposed to be a planet, or to belong to our solar system, until the year 1781. As no planet was suspected to exist beyond saturn, so none was sought for there; nor had the discovery of motion, in Uranus, the most distant connexion with any preconceived intention of such discovery: it was the result of accident alone. On the night of the 13th of March, in the year above mentioned, Herschel, who was a native of Hanover, and who resided in England, while engaged in a series of observations upon the parallax of the fixed stars, and regarding with attention several near the feet of Gemini, he was struck with the fact that one appeared larger than the rest, when seen through his telescope. As the fixed stars are not magnified by these instruments, the fact of its enlarged appearance, when once detected, fixed the observer's attention. The telescope with which this discovery was made was one of seven feet in length, of the reflecting form; and the eye piece in use at the moment was one which magnified only two hundred and twenty-seven times. Having, by subsequent observations, determined that the body in question had changed place, in relation to those by which it was surrounded, Herschel no longer concealed his discovery. But at this time he had no suspicion that he had discovered a *planet*. He wrote to the Royal Society, of which he was a member, stating the facts, and adding that his first impression was he had detected a small comet, without either tail or envelope; and in a subsequent part of his announcement he adds: "the sequel has

shown that my surmises were well founded, this proving to be the comet we have lately observed."

This announcement was communicated, by Maskelyne, the English astronomer, to Mons. Messier, and then the astronomers of Paris were at once engaged in observing the supposed comet, *and in calculating its orbit:* for Herschel furnished no calculations, whatever, of the orbit of his supposed comet; nor were his observations so made that any aid could be derived from them, in such calculations. Nor were they long in detecting the errour which Herschel had committed, in regard to the body in question. On the 8th of May, 1781, less than two months from the first discovery of Uranus, as a moving body, *Jean-Baptiste Gasper Bochart de Saron* ascertained that it was much more elongated from the sun than any of the other planets; and his extraordinary facility, in calculating cometary orbits, had thus early enabled him to know that the motions of this body did not conform to a parabolick curve. He then gave the first idea of a circular orbit; and this suggestion was carried out, and the orbit itself determined, by his co-labourer, Méchain, according to the method of Laplace.

Thus, through the combined agency of a most happy piece of unexpected good fortune, on the part of Herschel, in England, and the industry and mathematical skill of the Paris astronomers, a new planet stood revealed to the knowledge of mankind, belonging to our solar family, and yet revolving in an orbit so immensely distant as to envelop all the others, and to give to the known limits of the solar system an augmentation of dimensions almost beyond conception.

According to Herschel there are six satellites belonging to Uranus, which achieve their revolutions in their several orbits, round their primary, in the following periods of time, respectively:

The first achieves its siderial revolution in the space of

| | $5^d$ | $21^h$ | $25^m$ | $21^s$. |
|---|---|---|---|---|
| The 2d. | 8 | 16 | 57 | 47. |
| " 3d. | 10 | 23 | 3 | 59. |
| " 4th. | 13 | 10 | 56 | 30. |
| " 5th. | 38 | 1 | 48 | 00. |
| " 6th. | 107 | 16 | 39 | 56. |

These bodies are so small and so immensely distant, that there necessarily exists much uncertainty respecting them. The greatest certainty, by far, exists with regard to the 2d and 4th of these satellites, and they present some most extraordinary features, nowhere else met with among the bodies of our solar system. The planes of their orbits are almost perpendicular to the ecliptick, being inclined no less than 78° 58′; and in their orbits they move from *east to west*, or in the direction contrary to every other planet that is known to us, whether primary or secondary!*

It has often been averred—and it is necessary here to repeat the correction, because the errours in question are still found in the newest books—that Dr. Herschel discovered motion in Uranus through the agency of his noted forty feet telescope; and also that he recognised that body as a *planet*. For the promulgation of these errours, numerous works, of commanding influence, are responsible, not to enumerate a multitude of minor publications, some of them school books, and hence in the hands of many of our youth, which have given them currency until they have well nigh passed into proverbs. Dr. Herschel, himself, in his publications, upon these subjects, has given no authority for these fabulous creations of some unknown pen.

* Among those fixed stars that are known to have motions, in regular orbits, there is no such uniformity of direction; some of them being found to have a direct, and others a retrograde motion.

Herschel once supposed that he had discovered two rings, surrounding Uranus, like those which envelop saturn; but he subsequently abandoned all belief in their existence. They were evidently optical illusions; and it is highly probable that they arose from the defect of figure of the mirror of the forty feet telescope. Indeed this instrument, which has been so often and so constantly the theme of eulogy and admiration, seems never to have been of very extensive practical use, particularly where the *forms* of heavenly bodies were to be determined. The figure of the mirror was so defective that the images of the celestial bodies, which it produced, were greatly distorted; and for this reason the magnifying power used upon it seldom exceeded two hundred—high powers, of course, greatly augmenting the distortion. This telescope was taken down, some years since, and laid aside; for which no other, or more sufficient reason has been assigned, than that the *frame work, which supported it*, had become decayed! No farther use has been made of this instrument; a much smaller one having been erected in its place, at the time of its removal, which still occupies that position.

The following tables exhibit, at a single view, a variety of useful and necessary details, with regard to both the primary and secondary planets.

DISTANCES OF THE PLANETS FROM THE SUN.

| Names of the planets. | Distances, in miles, in round numbers. | Names of the planets. | | Distances, in miles, in round numbers. |
|---|---|---|---|---|
| Mercury, | 37,000,000 | Juno, | | |
| Venus, | 68,000,000 | Ceres, | the mean, | 261,000,000 |
| The Earth, | 95,000,000 | Pallas, | | |
| Mars, | 142,000,000 | Jupiter, | | 485,000,000 |
| Vesta, | 225,000,000 | Saturn, | | 890,000,000 |
| | | Uranus, | | 1,800,000,000 |

For more accurate results, the following table of the same may be referred to.

MEAN DISTANCES FROM THE SUN, THAT TO THE EARTH BEING 1.

| | | | |
|---|---|---|---|
| Mercury, | 0 .3870981 | Ceres, | 2 .7672450 |
| Venus, | 0 .7233316 | Pallas, | 2 .7728860 |
| Earth, | 1 .0000000 | Jupiter, | 5 .2027760 |
| Mars, | 1 .5236923 | Saturn, | 9 .5387861 |
| Vesta, | 2 .3678700 | Uranus, | 19 .1823900 |
| Juno, | 2 .6690090 | | |

VOLUMES OF THE SUN AND PLANETS, THAT OF THE EARTH BEING 1.

| | | | |
|---|---|---|---|
| The Sun, | 1,328,460 .00 | Vesta, | Unknown. |
| Mercury, | 0 .10 | Juno, | |
| Venus, | 0 .90 | Ceres, | |
| The Earth, | 1 .00 | Pallas, | |
| The Moon, | 0 .02 | Jupiter, | 1,470 .20 |
| Mars, | 0 .20 | Saturn, | 887 .30 |
| | | Uranus, | 77 .50 |

MASSES OF THE SUN AND OF THE PLANETS, THAT OF THE EARTH BEING 1.

| | | | |
|---|---|---|---|
| The Sun, | 337,086 .0000 | Vesta, | Unknown. |
| Mercury, | 0 .1664 | Juno, | |
| Venus, | 0 .9452 | Ceres, | |
| The Earth, | 1 .0000 | Pallas, | |
| The Moon, | 0 .0170 | Jupiter, | 315 .8926 |
| Mars, | 0 .1324 | Saturn, | 120 .0782 |
| | | Uranus, | 17 .2829 |

DENSITIES OF THE SUN AND THE PLANETS, THAT OF THE EARTH BEING 1.

| | | | |
|---|---|---|---|
| The Sun, | 0 .236240 | Vesta, | Unknown. |
| Mercury, | 2 .879646 | Juno, | |
| Venus, | 1 .047010 | Ceres, | |
| The Earth, | 1 .000000 | Pallas, | |
| The Moon, | 0 .715076 | Jupiter, | 0 .241190 |
| Mars, | 0 .930736 | Saturn, | 0 .095684 |
| | | Uranus, | 0 .020802 |

NUMBER OF FEET, PER SECOND, THAT A GRAVITATING BODY WOULD PASS THROUGH, IN FALLING, AT THE SURFACE OF THE SUN, AND OF THE PLANETS.

| | | | |
|---|---|---|---|
| The Sun, | 429 | Juno, Ceres, Pallas, | Unknown. |
| Mercury, | 12 | | |
| Venus, | 18 | | |
| The Earth, | 16 | Jupiter, | 42 |
| The Moon, | 3 | Saturn, | 15 |
| Vesta, | Unknown. | Uranus, | 4.2 |

TIMES OF ROTATION, UPON THEIR AXES, OF THE SUN AND THE PLANETS.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| The Sun, | 25d | 12h | 0m | 0s | Vesta, Juno, Ceres, Pallas, | Unknown. | | |
| Mercury, | 1 | 0 | 5 | 3 | | | | |
| Venus, | 0 | 23 | 21 | 19 | | | | |
| The Earth, | 1 | 0 | 0 | 0 | | | | |
| The Moon, | 27 | 7 | 44 | 0 | Jupiter, | 0d | 9h | 56m 37s |
| Mars, | 1 | 0 | 39 | 22 | Saturn, | 0 | 10 | 29 2 |
| | | | | | Uranus, | Unknown. | | |

TIMES OF THE REVOLUTIONS OF THE PLANETS.

| | Years. | Days. | | | |
|---|---|---|---|---|---|
| Mercury, | 0 | 87 | 23h | 14m | 30s |
| Venus, | 0 | 224 | 16 | 41 | 27 |
| The Earth, | 0 | 365 | 5 | 48 | 49 |
| Mars, | 0 | 686 | 23 | 30 | 42 |
| Vesta, | 3 | 66 | 4 | 0 | 0 |
| Juno, | 4 | 128 | 0 | 0 | 0 |
| Ceres, | 4 | 220 | 2 | 0 | 0 |
| Pallas, | 4 | 220 | 16 | 0 | 0 |
| Jupiter, | 11 | 315 | 12 | 30 | 0 |
| Saturn, | 29 | 161 | 4 | 27 | 0 |
| Uranus, | 84 | 29 | 8 | 39 | 0 |

ANNUAL PARALLAXES.

| | | | |
|---|---|---|---|
| Mercury, | 126″ | 14 | Jupiter, 9″ 59 |
| Venus, | 139 | 9 | Saturn, 5 42 |
| The Moon, | 27 | 1 | Uranus, 2 55 |
| Mars, | 18 | 6 | |

INCLINATION OF THE RESPECTIVE PLANETARY ORBITS TO THE ECLIPTICK.

| | | | | | |
|---|---|---|---|---|---|
| Mercury, | 7° | 78′ | Ceres, | 10° | 37′ |
| Venus, | 8 | 76 | Pallas, | 34 | 37 |
| The Moon, | 5 | 71 | Jupiter, | 1 | 46 |
| Mars, | 1 | 51 | Saturn, | 2 | 77 |
| Vesta, | 7 | 8 | Uranus, | 0 | 46 |
| Juno, | 13 | 5 | | | |

INCLINATION OF THE AXES OF THE SUN AND PLANETS TO THEIR ORBITS.

| | | | | | |
|---|---|---|---|---|---|
| The Sun, | 82° | 50′ | Vesta, } | | |
| Mercury, | — | — | Juno, } Unknown. | | |
| Venus, | — | — | Ceres, } | | |
| The Earth, | 66 | 52 | Pallas, } | | |
| The Moon, | 88 | 50 | Jupiter, | 89° | 45′ |
| Mars, | 61 | 33 | Saturn, | 60 | 0 |
| | | | Uranus, | — | — |

LEAGUES, IN ROUND NUMBERS, PASSED OVER BY EACH PLANET, PER MINUTE.

| | | | |
|---|---|---|---|
| Mercury, | 635 | Juno, | — |
| Venus, | 485 | Ceres, | — |
| The Earth, | 412 | Pallas, | — |
| The Moon, relatively to the earth, | 14 | Jupiter, | 178 |
| Mars, | 329 | Saturn, | 132 |
| Vesta, | — | Uranus, | 93 |

SATELLITES OF JUPITER.

| Mean distances, the demi-diameter of the planet being 1. | | | Duration of the revolutions. | | Mases of the satellites, that of the planet being 1. |
|---|---|---|---|---|---|
| 1st. | Satellite. | 6 .0485 | 1*d* | .7691 | 0 .000017 |
| 2d. | do. | 9 .6235 | 3 | .5512 | 0 .000023 |
| 3d. | do. | 15 .3502 | 7 | .1546 | 0 .000088 |
| 4th. | do. | 26 .9983 | 16 | .6888 | 0 .000043 |

SATELLITES OF SATURN.

| Mean distances, the demi-diameter of the planet being 1. | | Duration of the revolutions. |
|---|---|---|
| 1st. Satellite, | 3 .35 | 0*d* .943 |
| 2d. do. | 4 .30 | 1 .370 |
| 3d. do. | 5 .28 | 1 .888 |
| 4th. do. | 6 .82 | 2 .739 |
| 5th. do. | 9 .52 | 4 .517 |
| 6th. do. | 22 .08 | 15 .945 |
| 7th. do. | 64 .36 | 79 .330 |

SATELLITES OF URANUS.

| Mean distances, the demi-diameter of the planet being 1. | | Duration of the revolutions. |
|---|---|---|
| 1st. Satellite, | 13 .12 | 5*d* .893 |
| 2d. do. | 17 .02 | 8 .707 |
| 3d. do. | 19 .85 | 10 .961 |
| 4th. do. | 22 .75 | 13 .456 |
| 5th. do. | 45 .51 | 38 .075 |
| 6th. do. | 91 .01 | 107 .694 |

## CHAPTER EIGHTH.

### LAWS OF KEPLER.

We have heretofore contented ourselves, while treating of the planets, with stating that they describe, round the sun eliptical curves, more or less elongated; but we have not yet examined into the means of determining these orbits; nor have we investigated their nature.

The curves described by the planets always make an angle, more or less open, with the plane of the ecliptick, and they consequently cut this plane, at two points exactly opposite. These points are the nodes;

and a line joining these two points is the line of the nodes. This line determines the trace of the plane of the planet's orbit upon the ecliptick. Let us now suppose an observer to be placed upon the sun: it would be easy for him to know the precise instants of the passage of the planet through its nodes; which would take place when the planet should be upon a line passing through the node and the centre of the sun. As for an observer upon the earth; that is, out of the centre of the solar system, he can very well fix the moments of the passages of the planets through their nodes, although he cannot observe them, as from the sun, because the right line which joins them must successively assume various inclinations, by the effect of the sun's motion; yet it sometimes, though very rarely, happens that, the sun and the earth being upon the same line, the planet to be observed will be found upon the prolongation of that line. It will then be seen at the same point as the sun; the observer may fix its longitude, and several observations of this kind will determine if the node of the planet always corresponds to the same longitude, seen from the sun.

The node being found, to determine the inclination we seize the moment when the sun has the same longitude as the planet; we then obtain the latitude of the body, from which we deduce the inclination of the plane of the orbit.

After these data are obtained, in order to find the nature of the curve, we measure the duration of an entire revolution; which is done by fixing upon some point, one of the nodes, for example, and carefully computing the time which elapses between two successive passages of the planet through this point.

When we have thus obtained the duration of the revolution nothing remains but to fix, by means of the oppositions and conjunctions, the angular movement of the planet.

Having thus traced the orbits of the planets we learn,

1st. That all the planets move in ellipses, of which the sun occupies one of the *foci;*

2d. That the motion is more rapid in proportion as the planet is nearer the sun, so that the radius vector, or imaginary line joining the centres of the sun and planet, always describes equal areas in equal times;

3d. That the squares of the times of the revolutions are as the cubes of the grand axes of the orbits.

These are the laws of Kepler; and they serve as the basis of astronomy. We shall see, hereafter, how these laws contain the germ of the general law of attraction. These important laws have been verified in the case of all the planets; and they are found so perfectly exact that we no longer hesitate to fix the distances of the planets from the sun by the duration of their siderial revolutions: and we know that this method of determining distances affords us great exactitude, for it is always easy to determine, with precision, the return of each planet to a given point in the heavens, while it is very difficult to calculate, directly, its distance from the sun.

## UNIVERSAL ATTRACTION.

The laws of Kepler, which have rendered so important services to astronomy, in disclosing the wonderful relations of the celestial movements, were particularly calculated to excite inquiring minds to an investigation of the cause which presides over these movements. This discovery was reserved for the genius of Newton; but the details and the calculations by which he established the existence of this general cause would be useless to the pupil here; and we shall therefore limit ourselves to an exposition of the consequences which he deduced from the laws of Kepler.

1st. From the fact that the radius vector always describes equal areas in equal times, Newton deduced, and supported by calculations, the consequence that *the force which holds the planets in their orbits acts in the direction of the centre of the sun.*

2d. Kepler had shown that the orbits of the planets are ellipses, of which the sun occupies one of the *foci;* and Newton, from this, first inferred, and afterwards proved, *that the force which acts upon the planets is in the inverse ratio of the square of the distance of their several centres from that of the sun.* And,

3d. From the fact that the squares of the times of the revolutions are as the cubes of the transverse axis of the orbits, he deduced this consequence, namely, *that the force is proportional to the mass.*

From these several results it follows that the sun is the centre of an attractive power which acts in virtue of the foregoing laws.

Newton, who, after noting the attraction exercised by the earth, upon bodies at its surface, extended the agency of this attraction to the moon, subsequently concluded, from analogy, since the other planets retained their satellites in their several orbits, as the earth holds the moon in hers, that those planets must possess, like the earth, an attractive force; and that this force could be no other than one of the same nature as that which gives to the sun the power to cause to revolve around him, in well defined orbits, all the bodies belonging to the solar system.

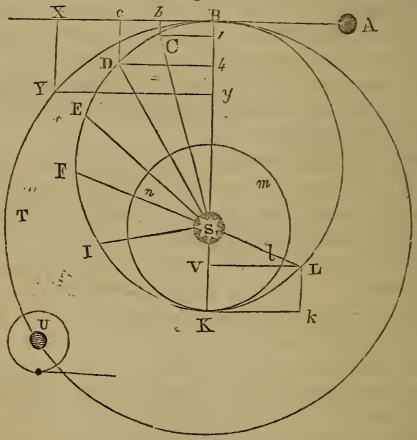
The several bodies which revolve around the sun are, like him, endowed with the power of attraction, and by carrying the analogy farther we arrive at this general result, which physicks has fully demonstrated, and of which the special form of the celestial bodies gives strong presumptive evidence, namely, *that all particles of matter mutually attract each other, in the*

*direct ratio of their masses; and reciprocally, as the squares of their distances.*

But, as the force of attraction, if it existed alone, would directly tend to assemble, in one mass, and there to retain, all the globes which the universe embraces, Newton supposed that the celestial bodies had primitively received an impulsion, in a right line, and that from the combination of these two forces results the curvilineal motion of the planetary bodies.

To illustrate this; If the body A, fig. 29, is projected upon the right line A B X, in open space, where it

Fig. 29.




shall encounter no resistance to enfeeble the impulsion which has been given to it, that body, under these circumstances, would continue, indefinitely, to move with the same velocity, and in the same direction. But if, on arriving at B, it is attracted by S with an adequate force, acting perpendicularly to its line of motion, it will be drawn from the right line A B X, and will de-

scribe around S the circle B Y T U. That the body may describe this circle, it is necessary that the projectile force with which it be impelled upon the right line A B X should be equal to that which it would have acquired, by gravity alone, in falling through half the radius of that circle.

That this body, when arrived at B, should describe the circle B Y T U, it is necessary that it should be so attracted by S as to fall from B to *y*, half the distance B X, in the time it would take to move from B to X by the effect of the force of projection alone. In this case, we may suppose A a planet and S the sun.

But if, while the projectile force carries the planet from B to *b*, the attraction of the sun cause it to fall from B to 1, the power of gravitation would be proportionably greater than in the previous case; and the planet would then describe the curve B C. When the planet, in this curve, shall have arrived at C. gravitation, which augments in the inverse ratio of the squares of the distances, will act more powerfully than at B, and thus cause the planet to descend with greater velocity, so as to make it describe the arcs B C, C D, D E, E F, F I, I K, in equal times: the planet moving, in this case, with much greater rapidity than before, it would necessarily acquire a great tendency to fly off in the tangent K *k*, or, in other words, its projectile force would, in this way, be increased to such an extent as would be sufficient to overcome the force of attraction, and thus prevent the planet's falling into the sun; or even from moving in the circle K *l m n*. The planet, then, would increase its distance from the sun, in following the curve K L B, but its velocity would gradually decrease from K to B, as it had previously increased from B to K, because the solar attraction would here be exercised in the opposite direction. Once more at B, after having lost, in moving from K to B the excess of velocity which it had acquired in

passing from B to K, the planet would still obey the same forces, and therefore again describe the same curve round the sun.

*A double projectile force balances a quadruple attractive one.* Suppose, then, that the planet, at B, had, towards X, an impulsion twice as great as we have assumed; that is to say, an impulsion which would cause it to pass from B to *c* in the same time we have supposed it to consume in passing from B to *b*. In this case it would be necessary that the force of gravity should be four times greater in order to retain the planet in its orbit; in other words, such force would require to be capable of causing the planet to fall from B to 4 in the same time that the projectile force would have carried it, in a right line, from B to *c;* otherwise the planet could not describe the curve B D, as shown in the figure.

As the planets alternately approach the sun, and recede from it, at each revolution, there is a little difficulty in conceiving how, in the former case, they should not continue this approximation, when once begun, until they fall upon the sun's surface; and how, in the second, they should not continue for ever to augment their distance from the sun; but this difficulty vanishes from the moment that we examine into the action of the moving forces, and their respective intensities, in the case in question. The planet, we have said, moved by a projectile force which would carry it from B to *b* in the time in which the sun would cause it to fall from B to 1, submits to the mutual action of these two forces and describes the curve B C. But when the planet shall have arrived at K, what will then be the action of these forces? K S being equal to the half of B S, the planet will be *twice* as near the sun; the action of gravity will then be *four* times greater, according to the principle already laid down. Consequently, it will cause the planet to fall from K to V,

in the same time that, at B it would have drawn it from B to 1; K V being four times greater than B 1. But the projectile force, at this moment, is such as to carry the planet, in the same time, from K to *k*, a space double that of B *b*, as shown in the figure; and consequently this force is here double what it was at B. Now, we have already stated that a double projectile force balances a quadruple attractive force; consequently the equilibrium, between the two forces, would not here be interrupted, and therefore the planet would continue its route from K to L, &c. in conformity with the resultant of these two forces. When the planet shall have reached the point B, it will then be again subject to the same forces which first caused it to describe the orbit just traversed; and as these forces continue to act with the same intensity as before, the planet will continue to describe, indefinitely, the same curve around S.

Such is the great principle of Universal Attraction. It is so exact that there are no perturbations, no deviations, however slight they may be, for which it does not account with the most rigorous precision. Astronomers have such entire confidence in the results of this principle that, when observations are found not to agree with the results of calculation, they invariably suspect such observations to partake of inaccuracy, rather than doubt the settled laws of attraction; and thus far, all results show that these suspicions have been just.

### OF THE MASSES OF THE PLANETS.

It is through the aid of the principle of attraction that we arrive at a knowledge of the mass and density of the sun, and of the several planets—both of which we have given, in their place—with much of the other knowledge we have of the several globes of our solar

system. In as much as the velocity of revolution of the satellites depends upon the attractive power of the primary planet, we are enabled to deduce their masses from this velocity. If a planet has no satellite, its mass is determined by the perturbations which other bodies produce in its movements.

The mass and the volume once ascertained, it is easy to obtain the density; as, for this result, it is only necessary to divide the mass by the volume.

Cavendish has determined the mass of the earth by another method, which, however, is no less dependant upon the principle of gravity. He suspended, from the extremity of a very fine thread, a needle which, in this situation, was in a condition to yield to the slightest attraction. Near this needle he placed a globe of lead, which of course attracted the needle. Under these circumstances he carefully determined the duration of the oscillations which he caused the needle to perform. These he subsequently compared with the oscillations of a pendulum, when subject to terrestrial gravity, alone, and from this comparison he deduced the relative proportion of the attractive force of the sphere of lead—the mass of which was known—to that of the earth, and thus he found the proportion which the mass of the leaden sphere bore to the mass of our globe.

Finally, we shall learn, while treating of the earth, that gravity has furnished the means of determining measures with a precision that is not attainable by any other method.

## CHAPTER NINTH.

### THE EARTH, ⊕.

We omitted to treat of the Earth, in detail, in its place among the planets, because a knowledge of the foregoing chapters was necessary, to the pupil, before entering upon this subject. We will now examine, successively, the figure, the dimensions and the movements of the earth.

### FIGURE OF THE EARTH.

Deceived by the illusion of the senses man long regarded the earth as a boundless plain. Subsequently this errour was slowly dissipated, by the observation of numerous facts. It was noticed, in the level countries of the east, in approaching very elevated objects, which were at great distances, that the summits of such objects were first visible, and that, as the distance to the objects lessened, more and more of the parts below became revealed to sight, while the base was always the part last discovered. These phenomena could not be the accidental result of the shape of the face of the country, or of any particular circumstance, for it was remarked alike in all directions, and in every place, and it was always the more sensible in proportion as the atmosphere was more pure. Subsequently the same observations were made upon the sea; and here the phenomenon was still more conclusive, since there were neither inequalities nor obstructions, of any kind, to favour any supposed deception: and yet it was evident enough that the surface of the ocean must necessarily conform to the general figure of the globe. At this day almost every one has either seen or heard that a vessel, on leaving shore appears to sink beneath the surface of the water, so that her lower parts disap-

pear first, and afterwards, successively, those which are more elevated; and last of all the tops of her masts. So persons on shipboard, when approaching port, first discover the tops of objects, on shore, but do not see their inferiour portions, or the surface of the ground upon which they stand, until much nearer to them. This shape of the earth is farther shown, also, by the facts that the tops of mountains are the parts first enlightened by the sun, in the morning, and are still illumined by the rays of that body, at night, after the sun is below the horizon. More recently, still, the convexity of the earth's surface has been *demonstrated*, by various methods:

1st. By the voyages of navigators who, after having made the tour of the earth, have returned to their point of original departure, by an opposite direction to that in which they departed;

2d. By astronomical observations; among others, that of the circular form of the shadow projected by the earth upon the disk of the moon, during an eclipse of this last body; and,

3d. By operations which have served to determine the dimensions of the earth; as, for instance, the direction of the plumb line, at different stations upon the earth's surface.

From proofs incontrovertible, then, we know that the earth is very nearly spherical: we say very nearly, because we shall soon see that it has the figure of a sphere, but flattened at the poles, and enlarged at the equator. We shall arrive at these facts while determining the dimensions of the globe; and we shall subsequently see that this form is a necessary effect of the earth's movement of rotation.

### DIMENSIONS OF THE EARTH.

The earth having sensibly the form of a sphere, it follows that if we know the length of a single one of

its degrees, by multiplying this by 360, we shall obtain the circumference, and hence the diameter, the surface, and the volume of the earth. This result, then, depends upon the determination of a single terrestrial degree. Now, to determine this, in a practical manner, the following method has been pursued: a space has been selected upon the earth, such, that perpendiculars, determined by a plumb line, at each of the extremities of this space will correspond to two stars situated one degree apart; and the space thus designated of course constitutes a terrestrial degree. Now, it is easy to see that where this exact distance is not readily to be had, no difficulty can arise from taking a greater or less space, as simple proportion will always give the exact length of a degree. It only remains, then, to measure, with precision, the base thus chosen. This has been done, with incredible exactness, by what is known as the trigonometrical method, but which we cannot illustrate here.

This practical determination of terrestrial degrees has confirmed the flattening of the earth, at the poles, and its enlargement, or swelling, at the equator. Indeed the degree, or the space constituting a degree, is not the same, in all latitudes: it is longer in proportion as we approach either of the poles, while it is at its maximum, at the equator: which clearly indicates a flattening, at the poles, and not an elongation there, as, by a singular errour, was once supposed.

The amount of this flattening, deduced from geometrical admeasurements, has given it as $\frac{1}{306}$, that is, that the polar diameter of the earth is $\frac{1}{306}$ less than its equatorial diameter: making a difference of something more than 26 miles. These measures are given, mathematically, by the movements of the moon, with much more precision than they can be determined by measures taken upon the earth's surface; for it is

a truth, however singular it may appear, that the very form of our globe is disclosed by certain inequalities in the movements of the moon. These inequalities would not exist, if the earth were a perfect sphere; and we are able, therefore, to determine the quantity of the earth's ellipticity, by mathematical results, deduced from observations of these lunar movements.

Gravitation has also furnished us the means of determining the oscillations of the pendulum; which vary, at different points of the earth's surface, with the variation of the force of gravity. The following are the precise measures of the earth, in miles and parts of miles:

| | Miles. | Decimals. |
|---|---|---|
| Diameter, at the equator, | 7925 | .648 |
| Diameter, through the poles, | 7899 | .170 |
| Mean diameter, | 7912 | .409 |
| Difference between the polar and equatorial diameters, | 26 | .478 |

This last is the exact quantity by which the figure of the earth deviates from a perfect globe, in its form.

The length of a terrestrial degree, determined by trigonometrical admeasurement, at the point midway between the equator and the poles of the earth, has been found to be $364492\frac{41}{100}$ feet. That degree which results from the arch of the meridian which crosses France, from Dunkirk to Barcelona, and which has since been extended to the island of Formentera, converted into the itinerary measures of different countries, gives the following results:

The geographical league of France is of 25 to a degree; the marine league is 20; each marine league is equal to three minutes of a terrestrial degree; $\frac{1}{3}$ of a league is equal to one mile, or one minute of the equator—this is the mile of England, or of Italy: the league of Spain, or of Holland, and the mile of Germany, are of 15; that of Sweden, of 12; that of Hungary of 10; and the Werst of Russia of 90, to the degree.

The entire surface of the terrestrial globe contains 25,790,440 square leagues, of which about three fourths are covered by the sea; and of the rest, scarcely one half is inhabited.

In this sketch of the dimensions of the earth we have not spoken of the inequalities of its surface; and for the reason that the highest mountains may be considered as insensible, relatively to the earth's entire volume; so that the surface of the globe, in despite of the innumerable asperities which it presents, may be comparatively regarded as infinitely more uniform than the surface of an orange.

### MOVEMENT OF THE EARTH.

The sphericity of the earth being established, and its dimensions known, we may now occupy ourselves with its motions. We will first demonstrate that it turns upon its own axis, and afterwards that it has, beside this, another motion, namely, that of translation through space, in an orbit round the sun.

### DIURNAL ROTATION OF THE EARTH.

All the celestial sphere appears to us to turn entirely round the earth once in twenty four hours, and the question arises, is this appearance of motion, in the starry heavens, real, or is it an illusion?

If we compare our earth to the other globes of our solar system, and not only to these, but to the infinity of fixed stars, which we have seen to be no other than suns, at least equal in magnitude to our own, and probably constituting centres to so many planetary systems, we are readily made sensible that the planet we inhabit constitutes but an imperceptible point by the side of these enormous masses; and this fact, alone, raises a very just doubt, in the mind, whether such an

atom can constitute the centre around which all this vast assemblage of immense globes perpetually revolves. But this doubt will give place to astonishment when we reflect upon the incredible velocity with which these vastly distant bodies must move in order to describe, in so short a period of time, such incommensurable circles. But a still greater difficulty presents itself to this theory; which is that, as the velocity of these bodies would require to be greater, in proportion as their distance from the earth is more, it would be necessary to admit that the earth attracts each of these bodies with a force augmenting in the ratio that its distance is increased: a known absurdity, since we have seen that the reverse of this is true, in the attraction of all bodies.

Upon this testimony, then, we are forced to reject the opinion that the earth is the centre of celestial motion; and we must next inquire whether this apparent revolution of the heavens may not be an illusion of our senses. In instituting this inquiry we are conducted to the supposition that the real motion is in the earth itself: and this once admitted, the phenomenon we are considering is all logically and easily explained.

But, accompanying the globe, as we do, in its revolution upon its axis, we are not sensible of motion, and therefore believe ourselves immoveable, while the stars appear to us to move in the contrary direction to that in which we are carried. The same is true if we place ourselves in a carriage, or on board a ship: objects then appear to be carried from us, and with a motion more rapid, in proportion as they are nearer to us. This illusion is most perfect when the velocity is very great; and as the persons in a ship feel not the motion by which they are carried forward, so we are insensible to the rotary motion of the earth, which is vastly more rapid, but which never encounters any obstacle or resistance, by which a shock can be pro-

duced, whereby that motion would be rendered sensible.

The rotary motion of the earth being thus rendered extremely probable by the natural and easy explanation which it gives of the phenomenon in question, and by the evident absurdity of the opposite opinion, it now remains for us to prove this motion, directly.

It has been contended that if the earth turns upon its axis, a body projected into the air should, in falling, come to the earth behind the point from which it rose: that a stone dropped from the top of a tower should not fall at the foot of the edifice, because the earth would have moved, during the time of the fall. This is an errour: experiments having proved that a projected body always partakes of any motion which that which projected it may have had. For instance, a person in a boat which is moving parallel to the shore, may toss into the air a ball, and catch it, as it descends although he has moved while the ball was in the air. Now, although it will seem to this person that he projected this ball vertically into the air, yet viewed from the shore, the ball will be seen to have been thrown obliquely forward. It is well known that a stone, dropped from the top of a ship's mast, when the ship is in motion through the water, will fall at the foot of the mast, just as if the vessel were at rest: and that a bottle filled with water, inverted, and suspended, on board a ship which is in motion, with a minute opening, for the water to escape, will empty itself, drop after drop, into another bottle placed exactly beneath it, although the vessel might move forward several feet during the time that each drop should employ in falling.

But there is another feature to this subject, and from that we may draw mathematical proof of the rotary motion of the earth. Of two bodies which describe, *in the same period of time*, two circumferences une-

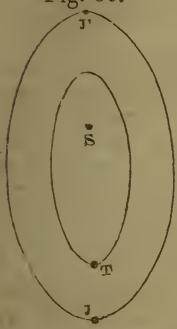
qually elongated from the axis of rotation, that which describes the most elongated, and consequently the largest, must necessarily move with greater velocity than the other. Suppose, then, that from the summit of a very elevated tower, a gravitating body be let fall. As the summit of the tower describes a greater circumference than the foot, because it is more elongated from the axis of rotation, it of necessity moves more rapidly; and as it would communicate this motion to the body thus let fall, such body would not follow the plumb line, in its descent, but would deviate towards the east. This has been demonstrated in the most convincing manner, by experiments.

Another demonstration of the rotary motion of the earth is borrowed from the transmission of light. But before offering this proof, we will establish the fact that light is not transmitted instantaneously, but that it requires time to pass through space.

Galileo attempted a solution of this problem, by direct experiment. To determine it, he prepared two lanterns, each furnished with a screen so adjusted as that by letting it fall it might instantly intercept all light from within the lantern. With one of these he repaired to a mountain, while an assistant, with the other, ascended a neighbouring height. Galileo had instructed his assistant that he should let fall the screen of his lantern the instant that the light of Galileo's lantern should disappear. He supposed that, if light moved progressively, he should detect a lapse of time, here, between the instant of shading his own light, and the disappearance of the light of his assistant. But in this he was deceived: the two lights disappeared at the same visible instant; which led him to the erroneous conclusion that light is transmitted instantaneously. We proceed to show that this erroneous result arose from the fact that the distance included in the experiment was not sufficiently great.

Figure 30, suppose S the sun, T the earth, J Jupiter at the moment of opposition, and J′ Jupiter at the moment of conjunction. If we observe two immersions of one of the satellites of Jupiter, one at opposition and the other at conjunction; and afterwards repeat this operation, in the inverted order, that is to say that, we observe an immersion at conjunction, and subsequently one at opposition, the time which will have elapsed between the first two observed immersions will be longer than the interval which will separate the last two; the difference being $16^m\ 26^s$. Now this difference can only arise from the time which is necessary to render the immersions visible; in other words, from the time which is necessary for light to pass from J′ to T; and as the operations have been made in inverted order, the difference of $16^m\ 26^s$ denotes the time in which light passes from J′ to T; or, to express it differently, $16^m\ 26^s$ is the length of time necessary for light to traverse the space in question; moving, as it does, with a velocity of 192,500 miles in a second of time.

Fig. 30.




The progressive transmission of light being established, we will now deduce from it our demonstration of the rotation of the earth.

If the earth is immoveable, we should not see the heavenly bodies at the moment they arrive upon the horizon or the meridian, but only after the lapse of so much time as is necessary for the rays of light, from them, to reach our eye.

If, on the contrary, the earth turns upon its axis, we should necessarily see these bodies at the instant of their arrival, either at the meridian or horizon; for,

by the effect of the movement of rotation the eye would be placed upon the line of such rays as had issued from these bodies at some previous moment, and which, at this instant, had reached the point of space occupied by our horizon.

Now, we do see these bodies at the instant of their arrival. The proof of this is, that the observed passages of our meridian, of Mars, for example, would be more or less hastened, or more or less retarded, according as this planet approaches the earth, or is elongated from it, if we saw it not at the instant of its arrival there; but no difference of this kind is ever observed: it is therefore proved that the earth has a rotary motion.

The earth having a circumference of almost 25,000 miles, at the equator, it follows that each point of its surface, there, passes over the circumference of a circle of equal dimensions. The velocity, then, of the surface of the earth, at the equator, is equal to that of a cannon ball.

Since the earth, then, has a rotary motion, upon its axis, which is now proved, it follows that it is, like all other bodies which have this motion, endowed with a centrifugal force, of which the intensity, according both to experiment and calculation, is in the ratio of the squares of the velocities of revolution. From this it follows that, under the equator, the centrifugal force is at its maximum, while at the poles of the earth it is nothing. The intensity of gravity, then, should be less under the equator than at the poles; and it has been clearly proved that this is so, by the oscillations of a pendulum, of the same length, at the equator, and at points distant from it. But in considering the solution of this problem, we must not forget that the difference, obtained in this way, is not *all* due to the agency of centrifugal force; for we have already seen that the distance from the surface to the centre of the

earth is greater at the equator than at the poles; and we have also learned that attraction acts in the inverse ratio of the squares of the distances.

We should, here, perhaps, add what has been, and still is, among astronomers, their explanation of the *cause* of the peculiar shape of the earth, namely, its enlargement, at the equator, and depression at the poles.

The earth, like all the other planets, we suppose, with the Geologists, to have been primitively fluid; at least this is an opinion which observations and theory concur in affirming, and which is generally admitted, at the present day. This assumed, suppose given to the earth a rotary motion round A B, fig. 31. The particles of matter situated in the right line A B, that is to say, upon the line of the poles, are not endowed with any centrifugal force, and consequently lose nothing of their weight. On the contrary, those particles situated in the line B C are subject to the influence of centrifugal force, which paralyzes, in part, the force of gravity, thereby rendering them lighter: a greater quantity of them, therefore, is necessary for maintaining the equilibrium.

Fig. 31.

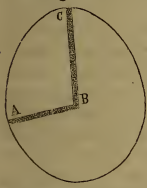
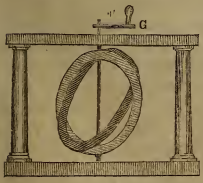



Fig. 32.




It is easy to suggest an experiment which will show that the velocity of rotary motion will produce a spheroid, flattened like that of the earth. Suppose two strips of pasteboard, or other flexible substance, bent into circles, and mounted upon an axis, as in fig. 32, so as to revolve with it. If these be made, by means of the crank, G, to

revolve slowly, they will experience no change of form; but if a rapid rotary motion be imparted to them, their poles will become depressed, and the circles will extend themselves upon the sides, or equator.

### ANNUAL MOTION OF THE EARTH.

We have seen that the earth revolves upon its axis, in 24 hours, and that the apparent revolution of the celestial sphere is only the effect of an illusion, produced by this motion of the earth. It remains for us now to inquire whether the annual motion of the sun is real, or whether it is only an appearance, caused by the displacement of the earth: for we have now learned to distrust the first evidences of our senses, in cases like this.

But we will first describe this motion. If we carefully observe the sun, each day, we shall see that it advances, every twenty-four hours, about 1° towards the east. Now, this 1° corresponds to four minutes of time; consequently the sun arrives four minutes later, each day, in the plane of the meridian; and in ninety days this daily sum amounts to six hours of time, which the sun will be later upon the meridian than the star with which it at first arrived there. At the end of a little more than 180 days, both the sun and this star will be in the plane of the meridian, at the same moment, but upon opposite sides of the earth, the one being in the *superiour*, and the other in the *inferiour* meridian. Finally, after 365¼ days, or one year, the sun, and the star with which it was first observed, will again be found on the meridian together, and upon the same side of the earth. The line which the sun may be said thus to have traced, is the ecliptick, of which the plane is inclined to the equator, 23° 28′ The most elevated points of the ecliptick have received the name of solstices, because the sun seems

to stop, in its progress, from the equator, at these points: and the equinoxes, that is to say, the epochs at which the days and nights are equal, take place when the sun is in the plane of the equator; which consequently occurs twice in each year. Such is the path which the sun appears to follow in the course of a year. But is this apparent motion real, or is it not rather the earth which traverses the ecliptick, and gives rise to the appearances which we witness?

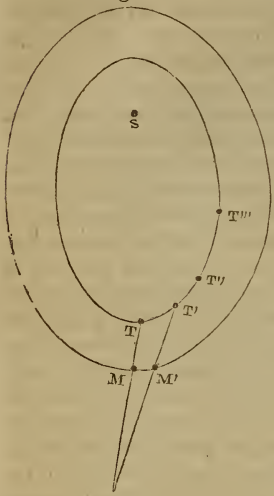
In answer to this question, if we resort to the inductions of analogy, we see, at once, that it is much more rational to admit that the earth, which we have already learned only lacks a revolutionary motion, in an orbit, to entitle it to place and rank among the planets, is really endowed with such a motion, than to suppose that the sun, with all its attendant array of planets, is in rapid revolution round the earth, in defiance of the laws of gravitation. But the probability of the movement of translation of the earth, already so great, attains the last degree of certainty when we deduce form observed phenomena the natural explanations and demonstrations which they afford, and which are such as wholly to remove all doubts upon the question.

Upon the supposition of the earth's immobility, in what possible manner can we account for the fact that the planets sometimes become stationary, and at others have a retrograde motion? And what is more easy, or natural than this explanation, upon the contrary hypothesis?

We have seen, in speaking of the planets, that these bodies appear to move, sometimes from west to east, sometimes from east to west, while at other times they appear stationary among the stars. Such are the phenomena. Now, suppose that the earth moves in the ecliptick, and let us examine into the results, upon this hypothesis. Figure 33, suppose S the sun, T the earth, and M Mars, for example. The earth,

moving more rapidly than Mars, would be at T′ when this planet would have advanced only to M′. Mars would then, by reason of the illusion of which we have already spoken, appear to have retrograded towards M. But when the earth has arrived at T″, the path it will have followed so inclines, in reference to that of Mars, that this latter planet will appear to be stationary. Finally, when the earth shall have reached T‴, the relative positions of the two planets will be such as to represent Mars as having again resumed its appropriate, progressive motion.

Fig. 33.




Such is, upon the hypothesis of the motion of the earth, the natural and easy explanation of the phenomena of the stationary and retrograde appearances of the planets—an explanation which is sought, in vain, in every other system.

Bradley, in endeavouring to determine the annual parallax of the fixed stars, discovered that they are not immoveable, but that they appear to describe, during the time that the earth employs in passing round the ecliptick, those which are in the plane of the terrestrial orbit, *right lines;* those which are in the plane perpendicular to this orbit, *circles;* and those which are in the intermediate planes, *ellipses*, more or less elongated, according as they are more or less near to the one or the other of these positions. This is the phenomenon of the aberration of light; and it has

furnished us with a new demonstration of the motion of the earth, through space.

Let us here recall to mind that light does not reach us instantaneously, from the stars, but that time is consumed in its transmission to us. This premised, suppose C A, fig. 34, a luminous ray falling perpendicularly upon the line B D. If the eye is at A, and in repose, it will see the object from which the ray proceeds, in the direction A C; but if the eye is in motion from B towards A, and if light is propagated with a velocity which shall be to that of the eye as the distance C A is to B A, then light will move from C to A while the eye moves from B to A. Now, every particle of light which renders the object visible, on the eye's arrival at A, is in C when the eye is at B. Join, then, the two points B and C, and suppose that the line C B is a tube, inclined to the line B D, and of such a diameter that only a single particle of light could find admission. It is evident that the particle of light from C, which would render the object visible when the eye, in its progressive motion, shall have arrived at A, passes through the tube B C, which accompanied the eye in its movement, and preserved its inclination. Now, if the particle of light reached the eye by passing through the tube B C, then the eye would see the object in the direction of this tube. If, instead of supposing the tube thus small we merely make this the axis of a larger one: the particle of light would then always pass through this axis, if the proper inclination of the tube were maintained, producing, of course, the same result. If we suppose the eye to move from D to A, the same results would follow; only that the tube, C D, would be inclined in the opposite direction.

Fig. 34.

It follows, from this, that if the earth moves, we see not the stars in their true position, but a little in advance of that position; and the difference between their real and apparent place is, to the sine of their visible inclination to the plane of the ecliptick, as the velocity of the earth is to that of light.

It is now easy to conceive that, the movement of the earth admitted, the fixed stars should present just the phenomenon observed by Bradley; and the explanation which we have given of this phenomenon, otherwise inexplicable, constitutes the most unanswerable proof of the revolution of our globe.

The earth, then, is no longer to us the immoveable centre, around which the whole universe gravitates; but it is found to be only a small planet of the solar system, obedient, like all the rest, to the laws of attraction. Its distance from the sun is about 95,000,000 of miles. Its annual revolution is accomplished in $365^{d}\ 5^{h}\ 48^{m}\ 49^{s}$, which is called its tropical year; but the time which it requires to complete its annual revolution, assuming a given fixed star as the point of departure and of arrival, is $365^{d}\ 6^{h}\ 9^{m}\ 12^{s}$, and this is designated the sidereal year. The rotation of the earth upon its axis is accomplished in 24 hours, which constitute the length of the natural day. The mean diameter of the earth is $7912\frac{409}{1000}$ miles. A point upon the equator moves, by means of the earth's rotation, nearly $\frac{1}{10}$ of a league per second, while the earth is translated through space, in its orbit, about seven leagues per second; which is but little more than half the velocity of Mercury, while it exceeds that of Uranus by more than four to one. The diameter of the earth's orbit is about 180,000,000 of miles. Farther details, of this kind, are rendered unnecessary here, by the tables which we have inserted in a previous part of this book.

# CHAPTER TENTH.

## OF THE SECULAR AND PERIODICK INEQUALITIES.

Bodies, as we have seen, mutually attract each other, according to certain laws, and in consequence of this, all the globes of our solar system should be disturbed, each by every other, and thereby subjected to an almost infinite variety of perturbations. This is precisely what astronomical research has shown to exist; and it constitutes one of the most unanswerable evidences of the accuracy with which the law of gravity has been determined. There is not one of these derangements, or inequalities, however minute, of which this law does not render the most rigorous appreciation.

The irregularities which the planets and their satellites experience, in their movements, have received the name of *inequalities*. These have been divided into *secular*, and *periodick* inequalities: not that the first are, in fact, less strictly periodick than the last, but only because these are not perfected except after the lapse of vast periods of time, while the last recur at much shorter intervals.

Nevertheless, these derangements are all limited, and have bounds set to them, which they never can exceed. The curves described by the planets may be more or less irregular, may approach to, and recede from the circular form, but the distance from the sun is constant, and invariable: the angle of inclination of the axis to the orbit may experience variations; but these can never extend beyond certain limits.

We propose, here, to speak only of the most remarkable inequalities of the moon and the earth.

## LUNAR AND TERRESTRIAL INEQUALITIES.

When the moon is in conjunction, that is to say, when, by reason of its movement of revolution, it is

placed between the sun and the earth, it is of course nearer the first of these bodies than when in the opposite situation, and the solar attraction acting with increased energy, in this case, the distance of the moon, from the earth, is thereby augmented. On the contrary, when the moon is in opposition, that is to say, when the earth is between the moon and the sun, this last body, attracting the earth more strongly, elongates it from its satellite, the moon. In the quadratures the case is still different: the action of the sun, then, leaves that of the earth to preponderate. Now the immediate effect of these derangements is to exercise a control over the velocity of the moon; and by them its movement is retarded, from the conjunction to the first quadrature, and accelerated from this quadrature to the point of opposition. The velocity then diminishes to the second quadrature, and is afterwards augmented from this point to that of conjunction. These inequalities are called *variations*.

Nevertheless, as the moon accompanies the earth, in its movement round the sun, and as the earth, in this movement, sometimes approaches the sun, and sometimes recedes from it, it is readily seen that this variation in the distances must produce modifications in the phenomena which we have described. This new species of inequalities has received the name of *annual equation*.

We have already seen, in treating of the moon, that its nodes move, upon the ecliptick, from east to west, at the rate of 19° .3286 per year, which would constitute an entire revolution in 18 years, 7½ months, about; or more exactly, in 6788 days .54019. This motion of the nodes of the lunar orbit, and the variations of its inclination to the ecliptick, are due to the action of the sun; for, when the moon, in its motion of revolution round the earth, approaches the plane of the ecliptick, the force of the sun's attraction hastens

this approach, and thus anticipates the moment when it would cut the plane of the ecliptick. From this arises the *retrograde movement of the nodes*; and the change of the inclination of the moon's orbit to the ecliptick.

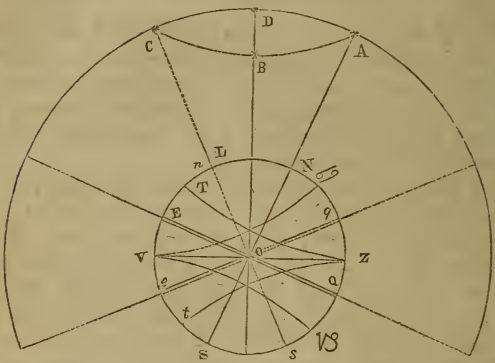
The attractive force of the earth, upon the moon, varies in intensity, according as this last is in apogee or perigee, and consequently giving more or less influence to the solar attraction. From this cause arise elongations and contractions in the lunar orbit. These inequalities are called *evections*.

But the most remarkable of these inequalities is *the precession of the equinoxes*. The sun does not cut the celestial equator, every year, at the same point. If on a certain day it cuts it at a given point, the same day of the following year it cuts it at a point situated 50″ .103 to the west of the first, thus arriving at the equinox $20^m\ 23^s$ before having completed an entire revolution of the heavens, from one fixed star to the same again. Thus the tropical year, or the true year of the seasons, is shorter than the sidereal year. The precession of the equinoxes is an effect of the solar attraction, that acts with more intensity upon the increased quantity of matter at the equator, which it tends to draw into the plane of the ecliptick, but which maintains its inclination by the effect of its motion of rotation. Retrograding each year, in this manner, towards the west, by the quantity 50″ .103, the equinoxes make an entire revolution in 25,867 years. Thus *Aries*, the Ram, ♈, which formerly corresponded to the vernal equinox, is now 30° west of it; although, by the conventional language of astronomers, it is always spoken of as denoting this equinox.

The retrograde movement of the equinoctial points causes the axis of the earth to describe, by virtue of a conical movement, a small circle, of which the diameter is equal to twice its inclination to the ecliptick,

that is 46° 56′. Suppose, fig. 35, N Z S V L the earth; its axis prolonged to the stars, and terminating at A, the actual north pole of the heavens, which is

Fig. 35.




vertical to N, the north pole of the earth: suppose, farther, E O Q the equator, T Z the tropick of Cancer, and V ♍ that of Capricorn: V O Z the ecliptick, and B O its axis, which should be considered as immoveable, because the ecliptick always passes through the same stars. But, as the equinoctial points retrograde in this plane, the axis of the earth, S O N, is in motion, upon its centre, O, as a pivot, in such a manner as to describe the double cone N O *n*, and S O *s*, around that of the ecliptick B O, in the time which the equinoctial points move round this plane, that is, in 25,867 years; and in this long interval the north pole of the axis of the earth describes the circle A B C D A among the stars, round the pole of the ecliptick, which remains immoveable, in the centre of the circle. The axis of the earth being inclined 23° 28′ to that of the ecliptick, the circle A B C D A, described by the north pole of the axis of the earth, prolonged to A, is near

46° 56′, or double the inclination of the axis of the earth. Consequently, the point A, which is at present the north pole of the heavens, and very near to a star of the second magnitude, in the end of the tail of the Little Bear, will be abandoned by the earth's axis which, retrograding one degree in $71\frac{2}{3}$ years, will be directed towards the star at the point B, in $6,447\frac{3}{4}$ years; and, in double that time, or $12,895\frac{1}{2}$ to the star, or point C, which will then be the north pole of the heavens. The present position of the equator, E O Q will then be changed to *e* O *q;* the tropick of Cancer from T Z to V ♋, and that of Capricorn from V ♑, to *t* Z. The sun, in the part of the heavens where it now is upon the terrestrial tropick of Capricorn, and produces the shortest days and the longest nights, in the northern hemisphere, will then be upon the terrestrial tropick of Cancer, giving the longest days and the shortest nights. This effect cannot be fully realized until the lapse of 12,895 years, reckoning from the point C; or rather, if we count from the point of departure A, after 25,867 years, the period necessary for the north pole to make one complete revolution, and return to the point of the heavens vertical to that which it now occupies.

Bradley having discovered the aberration of light, was pursuing farther observations for its verification when he perceived that the axis of the earth inclined, sometimes more and at others less to the ecliptick, causing the like variations in the inclination of the planes of the ecliptick and the equator, and describing, around the mean pole, as a centre, a small ellipse of which the major axis subtends an arch of the celestial sphere, of 20″ .153, and the minor axis one of 15″ .001. This ellipse is described in the exact period of the lunar cycle, that is to say, in very nearly eighteen years and seven months. The period of nutation being precisely that of the movement of the nodes of the moon, these two phenomena are necessarily allied.

It is, indeed, the attraction of the moon, acting with more intensity upon the equatorial regions than upon the poles, which causes this phenomenon of *nutation*.

Finally, beside the two inequalities which we have described, in the movements of the earth, and which are the two principal ones to which this planet is subjected, there is one other, of great importance, and which is the result of all the attractions which the planets collectively exert upon it. This is the gradual displacement of the plane of the ecliptick in the heavens, and the diminution of its inclination to the equator, by a quantity equal, or very nearly so, to 52″.1154 per century; being about one hundredth of the precession, namely, ½″ per year, 1′ in 115 years, and 1° in 6,900 years.

This change of obliquity in the inclination of the equator to the ecliptick, is confirmed alike by the observations of ancient, compared with modern astronomers, and by calculations. Modern astronomers have assured themselves of its truth by comparing the present positions of stars, relatively to the ecliptick, with those which they occupied, in relation to it, in the times of the earliest observations that we possess. Observations have farther shown that those stars which, according to ancient records of their positions, were situated to the north of the ecliptick, near the summer solstice, are now more advanced towards the north, and more elongated from this plane; while some, that were farther south, are now found comprised in the plane, and others, still, have passed to the north of it.

It is this motion, so well demonstrated, that has been so often, in books of science, as well as elsewhere, asserted to be perpetually progressive, and by the agency of which the equator and the ecliptick it is said have formerly been made to coincide, as they will again hereafter do. But Laplace has clearly demonstrated that this diminution of the obliquity of the ecliptick can-

not be continuous; but that, after a certain period, this motion becomes first retarded, and finally entirely arrested; after which a motion *in the opposite direction* ensues. In short, this movement he has shown to be a fixed and constant vibration, perpetually progressing either one way or the other, thus fully balancing itself, and never exceeding a fixed limit of between one and three degrees.

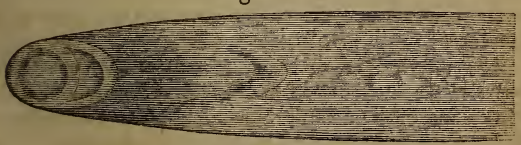
## CHAPTER ELEVENTH.

### OF COMETS.

We have next to devote our attention to a class of bodies which have given rise to a great variety of dissonant opinions. These are *Comets*, a species of celestial bodies of which the appearance of one has, in all former time, struck the mass of mankind with astonishment and fear.

But, before entering upon an examination of these bodies, some definitions of them, and of the several parts of which they are constituted, are necessary. As a farther aid to the pupil, in understanding the definitions which follow, the drawing, fig. 36, exhibiting

Fig. 36.



Comet of 1680.

the appearance of the comet of 1680, is given: but it must not be forgotten that these bodies are greatly diversified, and bear little resemblance to each other, while the same comet seldom maintains an entirely un-

changed appearance, even for so long a period as a single night.

The word *Comet* signifies a *hairy star*, and was originally adopted because it was supposed that all comets had this appearance; and although later observations have shown that this is not so, particularly as regards the tail, yet the name, having been so long in use, is retained.

The central part, which varies both in size and brightness, is called the *nucleus*.

The cloudy or hazy appearance, which in many comets surrounds the nucleus, is called the *envelope*.

The luminous trains, by which the greater part of comets are accompanied, were formerly designated *beard*, or *tail*, according as they preceded or followed the comet, in its motion. Now, however, the term *tail* is applied to all these appendages, in whatever direction they may project from the nucleus.

The nucleus and its envelope are collectively called *the head of the comet*.

Modern astronomers do not class among the number of essentially distinctive characteristicks of comets, either the envelope or the tail. According to them, any heavenly body is a comet which *has a proper motion, that is, has a motion of its own, and passes round the sun in an ellipse of so great eccentricity that it ceases to be visible from the earth, during some part of its revolution.*

The observations simultaneously and daily made upon different parts of the earth, at great distances from each other, and the participation of comets in the general revolution of the celestial sphere, permit of no farther doubt that comets are permanent, celestial bodies, and not meteors, engendered in our atmosphere, as was formerly supposed.

For a long period it was thought that comets followed no regular movement; that they were not sub-

ject to the laws which regulate and govern the other celestial bodies, but that they wandered from system to system, through the immensity of space. But since the discoveries of Kepler investigations have been made to know if these bodies are exempt from his laws, and also to determine their orbits. For this last determination it is sufficient to know three positions of the comet, 1st. *The longitude and the inclination of the node;* 2d. *The longitude of the perihelion*, and 3d. *The perihelion distance:* and to these data must be added whether the motion be *direct* or *retrograde*, in as much as these bodies, unlike the planets, move in every direction. By these means the curves which several comets describe have been determined; which has disclosed the fact that they move in ellipses of very great eccentricity, of which the sun occupies one of the *foci.* Nevertheless, comets having been anciently but little observed, and that very imperfectly, most of the elements necessary to the determination of their identity are wanting, which renders it very difficult to assign, to many of them, their period of return. It is not, indeed, *impossible* but some of them move in parabolick orbits, that is, in curves open at the end farthest from the sun, in which case, of course, they could never return towards the sun; but, while the *possibility* of this is admitted, because no law is known to forbid it, yet there is no good reason to suppose such a case ever existed; while it would furnish evidence of imperfection and derangement, in the celestial mechanism, of which no parallel is to be found.

As the physical circumstances of form, size, light, &c. of comets often materially vary, even in periods of only a few days, they can never be recognised, by any of these characteristicks, as the same body which was previously seen. For the purposes of such recognition the *parabolick elements* of the orbit are alone depended upon. But will the identity of two comets,

appearing at different epochs, be always infallibly determined by this means?

If the parabolick elements of two comets are different, we are still far from being certain that the two bodies are not the same; because, in passing near a planet, a comet may be so deranged in its course that its curve, or orbit, after such derangement, may be entirely changed. On the contrary, if the orbits of the two comets which are compared, have very nearly the same parabolick elements, their identity is thus rendered highly probable. Still it is not *impossible* that two different comets may describe two curves, similar in form and position; but when we consider how many different elements and circumstances enter into the similitude, we are not easily dissuaded from the belief that two comets, which appear at different periods, with the same elements, are one and the same body.

For the purpose of furnishing to astronomers, as far as possible, the means of determining, when a comet appears, whether it is one that has been previously observed, there exist catalogues of all the comets, in which are regularly recorded all their parabolick elements, so far as they are known. These elements are still very few in number, good observations of comets being entirely modern. Consequently there are, to the present time, but three comets whose regular, periodick return is known.

### COMET OF 1759.

The astronomer Halley having calculated, in 1682, the parabolick element of a comet which appeared in that year, was struck with the analogy which he found to exist between his results and those obtained by Kepler, for a comet which appeared in 1607. He next recurred to observations still more ancient, and there

discovered that the elements of a comet observed by Apian, in 1531, bore a very strong resemblance to his own. His inference was that this was the same comet, which had re-appeared at very nearly equal intervals of time, that is to say, about seventy-six years; and from this data he hazarded the prediction that this comet would return towards the end of the year 1758, or at the commencement of 1759. But Clairault having calculated, with great patience and labour, that the comet would be retarded 618 days by the attraction of Jupiter and Saturn, it finally arrived at its perihelion on the 12th of March, 1758. This comet is the first one of which the return was predicted, and that prediction verified.

Damoiseau, one of the Bureau of Longitude, of France, calculated the period of this body's return, in 1835, and fixed its perihelion passage on the fourth of November. Pontécoulant, another eminent French mathematician, who made the like calculations, first fixed on the seventh of November as the period of its passage. He afterwards, by a more complete and rigid valuation of the disturbing action of the earth, and by the substitution of a new value for the mass of Jupiter, carried forward the period of its passage to the thirteenth of the month. The actual passage took place, according to observation, on the sixteenth. This difference of only three days, in a period of more than seventy-six years, implies an accuracy which has astonished even astronomers. When it is considered how many causes of disturbance all comets are subject to, and how many of these, in the case of comets of so long a period, may be wholly unknown to us, such as the action of other planets, beyond uranus, of which we have no knowledge, or the action of other comets there, equally unknown to us; and above all, when we reflect that a knowledge of the exact weight of the sun, and of every planet in our solar system is abso-

lutely necessary to an accurate solution of the question here under examinaton, the only wonder is that a result so nearly accurate should have been obtained.*

## COMET OF 1770.

This comet was discovered by Messier, in the month of June, 1770; and Lexell found that it had, in five years and a half, described an ellipse of which the transverse axis was only three times the diameter of the earth's orbit. Great astonishment was manifested at this, namely, that a comet which, with so short a revolution, might often have been seen, and still was not perceived before the discovery of Messier; and this astonishment was redoubled when, at the end of five and a half years, it failed to return and again traverse the elliptical orbit assigned to it by Lexell. The causes of this mysterious disappearance, which gave rise to so many sarcasms, good and bad, at the expense of the astronomers, for their *lost comet*, are now fully and clearly known; although at that period they were not. These causes are found to originate in the law of universal attraction, of the truth of which they have furnished renewed confirmation. Lexell had remarked that in 1767 and 1779 this comet approached very near to Jupiter, whose powerful attraction had diminished, in 1767, the perihelion distance of its orbit, so as to bring the comet within view of the earth in 1770, by withdrawing it from its previous orbit, where it was invisible, from the earth; and afterwards, namely, in 1779, the influence of the same planet, acting in an opposite direction upon the comet, increased its perihelion distance to such a degree as to carry the comet again beyond our sight. Laplace submitted these suggestions to analysis, and demonstra-

* For more minute details of the difficulties which surround this question, see appendix.

ted that such had been the result of the attraction of Jupiter, upon this comet, at different periods. The appearance, then, of this comet, *for the first and last time*, in 1770, is fully explained, when we add that its return to its perihelion in 1776, took place during daylight, which alone prevented the inhabitants of the earth enjoying a second view of a body whose strange disappearance caused so much remark.

### COMET OF A SHORT PERIOD.

This comet was discovered at Marseilles, by Pons, on the 26th of November, 1818. Its parabolick elements, which were determined by Bouvard, caused it to be recognised as the same body which was seen in 1805, and Encke demonstrated that it completed a revolution in its orbit, in 1,200 days, or about $3\frac{3}{10}$ years; and records of previous appearances of this comet confirm these calculations.

### THE COMET OF SIX YEARS AND THREE QUARTERS.

This comet was discovered by Biela, at Johannisburgh, on the 27th of February, 1826. Gambart, who discovered it at Marseilles a few days after, determined its parabolick elements; and by comparing these with previous records, he learned that the same body had been observed as early as 1772, and again in 1805.

This is the comet which so greatly frightened many of the people of both Europe and America, because some one had announced that it would come in contact with the earth, on its return to the sun, in 1832. It is true that this comet did on the 29th of October, cross the earth's orbit, or path, at the point where the earth arrived on the 30th of November, following. By recurring to the mean velocity of the earth, in its

orbit, which is about 1,620,000 miles per day, we shall see that when this comet passed through the earth's orbit, the earth itself was at a distance of more than 48,000,000 of miles. In 1805 the same comet passed within about one tenth part of the distance from the earth, that it did in 1832, but without the slightest visible effect, of any kind, upon our globe. We shall speak, hereafter, of the possibility of a collision between the earth and a comet.

### PHYSICAL CONSTITUTION OF COMETS.

This branch of cometary astronomy is not far advanced; yet we will proceed to make known the state of the science in regard to the *envelope*, the *nucleus* and the *tail* of comets. Among all those comets which have been observed, to the present period of time, a great number have no perceptible tail; several present no apparent nucleus; but all exhibit that cloudy or hazy appearance which is known by the name of envelope.

The matter composing this envelope is so rare and transparent that the most feeble light is not obstructed by it; and consequently the smallest stars are not obscured by this part of a comet, when passing before them.

In such comets as have a nucleus, those parts of the envelope which are nearest to it are usually rare, very transparent, and but feebly luminous. But, at a certain distance from the nucleus, the envelope becomes all at once much enlightened, so as to form a luminous ring round the comet. Sometimes two, and even three of these rings are visible, concentrically arrayed, with dark spaces between them. These rings are, of course, an optical illusion, that which appears a ring, in projection, being, in reality, a spherical envelope.

When the comet has a tail this ring has the appearance of a semicircle, of which the convexity is turned towards the sun—when the tail is opposite the sun—and from the extremities of which issue the most luminous portions of the tail.

The ring of the comet of 1811, was 10,000 leagues in thickness; and its distance from the nucleus was about 12,000 leagues. The comets of 1807 and of 1799 had each two rings, of 12,000 and of 8,000 leagues in thickness.

We have said that there exist comets without apparent, or visible nucleus: these we cannot doubt are mere globes of gaseous matter; but there are many which present nucleuses very similar to planets, both in form, and in the appearance of their light. This was the case with Halley's comet, or the comet of 1759, as seen at Buffalo, at 7 o'clock on the evening of the 21st of October, 1835. Observed, on that occasion, with the aid of an acromatick telescope, under a magnifying power of sixty, "the nucleus was very distinct, and well defined; its diameter three fifths the mean diameter of Jupiter, under the same power, and of a colour midway between Mars and Jupiter."* At no other time, however, did the observer of this detect the same, or nearly the same, appearances in this comet, during its approach to the sun, in 1835. These nucleuses are usually very small; yet occasionally there is one of great size; and they have been measured of from eleven, to 1089 leagues in diameter.

Some astronomers have attempted to prove, supporting their positions by observations, that the nucleuses of comets are always transparent, or, in other words, that all comets are only simple masses of vapour, or gaseous matter. But, not only do the observations cited in support of this opinion prove nothing

* Observer's notes.

in favour of the positive terms in which the opinion itself is expressed, but they are in formal opposition to other observations, no less worthy of confidence. From a careful examination of all the observations extant upon this subject, it seems most probable that there are some comets which have actually no nucleus; others, of which the nucleus is perhaps wholly, or in part, transparent; and others, still, which are very brilliant, of which the nucleus is probably solid and opaque.

As to the tails of comets, science possesses very little certain data respecting them.

These luminous trains are perhaps most frequently placed nearly behind the comet, as seen from the sun, but they almost always deviate some degrees from this right line, and occasionally they have been seen forming a right angle with it. The tail, when nearly behind the comet, as seen from the sun, usually inclines somewhat towards the region which the comet is leaving. This has been supposed, by many, to be caused by the resistance of a very rare, invisible medium, called *ether*, which has been imagined to occupy the regions of space, beyond our atmosphere, and which is supposed to act more strongly upon the light matter of the tail than upon the more solid parts of the head of a comet. It has been farther urged, in favour of this hypothesis, or of its probability, that the inclination of these tails, which has been mentioned, is greater, in proportion as the distance from the head of the comet increases. But we must not forget that this theory is strongly discredited, if not absolutely disproved, by the fact that comets' tails have formed almost every possible angle with the right line joining the sun and comet, and that some comets, as that of 1824, have had one appendage of this kind tending from the sun, *and another projected directly towards that luminary.* There have also been,

as we shall soon see, comets with a still greater number of tails, and of course forming very different angles with this line.*

The tail of a comet enlarges in width, in proportion to the increase of distance from the head; and the centre of its width, throughout its entire length, is usually much darker than the rest; and this has often been supposed to be the shadow cast by the head of the comet. But this explanation is manifestly defective, as it is wholly inapplicable to all those tails which are not opposite to the sun. This phenomenon is far better explained by supposing the tail of a comet a hollow cone, of which the envelope has a certain thickness. Now, if this is so, we readily see that the eye would encounter more of the nebulous particles of which this envelope is formed, near the borders of the cone, than in its centre; and as the intensity of light is in the ratio of the number of these particles, the existence of the two bands of light, upon the borders, with an interval between them, comparatively obscure, is easily explained.

As we have said above, comets have sometimes had several tails. That of 1744, for example, on the 7th and 8th of March, had no less than *six* of these appendages, perfectly distinct, and separated from each other by spaces, as dark as other portions of the heavens. They were each about four degrees broad, and were spread out like a fan.

The tails of comets are sometimes of enormous dimensions. Some of them, as those of 1680, 1769, and 1618, were so long that when the comets were in the zenith their tails extended quite to the horizon. The tail of the comet of 1680, was computed to have extended more than 96,000,000 of miles; a distance greater than that of the earth from the sun!

* For a more full and detailed examination of this subject, and the evidences connected with it, see appendix.

But what are these tails of comets? How are they produced? What are the causes which so constantly modify and change their forms? What are those which control the formation of the envelope, and of the concentrick rings which sometimes surround the nucleus? None of these questions have ever yet been resolved, in a satisfactory manner; nor can they be, in the present state of our knowledge.

The envelope of comets would seem, at first thought, to be nothing more than a mass of vapour, disengaged from the nucleus, by the action of the sun; and such has been the opinion of Newton, and others. But this explanation, simple as it is, renders no account of the formation of the concentrick rings, round the nucleus, sometimes visible and sometimes not; nor of the variable positions of the envelope and tail, relatively to the sun, nor of the augmentation and diminution of the volume of these, &c.

Upon this last point, however, a theory has not been wanting. Heveleus advanced the opinion that the envelope augments in diameter, as the comet recedes from the sun; and Newton explained this result by supposing that the tails of comets, being formed, as he thought, from their envelopes, these last should diminish, in volume, in proportion as they approached the sun; and, reciprocally, should augment in dimensions, after the passage of the perihelion, when the material of the tail is again returned to the mass of the envelope. Nevertheless, it appeared difficult to admit that a gaseous mass should dilate itself in proportion as it became elongated from the sun, and consequently was passing into a region of greater cold; and the important remark of Heveleus obtained but little favour, until the comet of a short period gave confirmation of the *fact*—whatever may be the cause.

During the last appearance of Halley's comet, it was observed, at the Cape of Good Hope, by the

younger Herschel, after its perihelion passage. He says of it, then, that its physical aspect was entirely changed. For a long time *it had no tail.* The parabolick envelope of the head was formed under his very eye, as it were, with so great rapidity that its visible volume, which was well defined, was more than doubled in the space of twenty-four hours, computing from the morning of the 26th of January, 1836! On this occasion, in repeating, after an interval of three hours, the micrometick observations of the well defined parts that it had when he commenced, he found an augmentation of their linear dimensions, amounting to one *sixteenth* of their entire size! This extraordinary dilation continued until the paraboloid became so great and of so feeble a light as finally to disappear, entirely, leaving only the nucleus and the tail visible. Another, and very singular particular was the existence of a very small *interiour comet*, having a head and tail complete; its nucleus being that of the general mass. This dilated less rapidly than the envelope. Before observations ceased the tail itself became invisible. On the other hand, Valz, satisfied himself, after careful research and examination, that while some comets *contract*, when approaching the sun, others do not, but on the contrary, *dilate;* and that of this latter class is the comet of Halley.

Kepler thought that the formation of the tails of comets was the result of the impulsion of the solar rays, which detached the lighter portions of the envelope, and forced them to a distance behind the comet. But to render this explanation admissible it is first necessary to prove that the solar rays are endowed with an impulsive force; for the most delicate experiments have hitherto failed to render such force perceptible. This force shown and admitted, it will still remain to be demonstrated why the tail is not always situated opposite to the sun; why there are sometimes several

tails, making, one with another, so great angles; why they form, and again vanish, in so short periods of time; why some of them have a rapid rotary motion; and finally, why some comets, of which the envelope seems very light and delicate, exhibited no trace of this appendage.

A crowd of other theories, more or less ingenious, have been proposed; but they all equally fail to explain the phenomena.

Are comets self luminous bodies, or do they reflect the borrowed light of the sun, like the planets? This important question has not yet received a complete solution; but there exist several methods by which such solution may be obtained. If observation should detect the phenomena of phases, in comets, this would dissipate all uncertainty. In default of phases, the phenomena of the polarization of light may conduct to the desired result. A third method, of which the application would probably leave no doubt, is the following:

Suppose a detached and isolated luminous point, without sensible dimensions, which sends forth, upon every side, into space, particles of light. If we receive, at the distance of a yard, for instance, these luminous particles upon the surface of a sphere, of one yard radius, they will be uniformly diffused over this surface. If we receive them at the distance of 2, 3, or 100 yards, the spheres, of course will be of 2, 3, or 100 yards radius, and the luminous particles will here, also, be uniformly diffused over the surface upon which they are received, *but they will be farther from each other, in proportion to the increase of the surfaces of the spheres.* Now, geometry demonstrates that the surfaces of spheres increase proportionally to the squares of their radii: the separating distances, then, between the luminous particles would also be proportional to the squares of the radii of the spheres; or, in other words, to the squares of the distances at which the

luminous particles are received upon the surface of the sphere. And, as the intensity of the light which enlightens an object is in the ratio of the number of luminous rays which fall upon it, we thus arrive at this law, namely, that *the luminous intensity of a point diminishes proportionally to the squares of the distances.*

We have supposed, in the above case, a luminous point, without sensible dimensions: let us now elarge this point, so as to give it an appreciable extent of surface.

It is evident that each point of this enlightened surface, like the isolated point of which we have spoken, will send forth light which will be enfeebled in the inverse ratio of the squares of the distances; yet the number of luminous points being augmented, the total quantity of light emitted will be greater: from whence flows this consequence, namely, that at equal distances the intensity of the light is in proportion to the number of enlightening points.

We have, then, arrived at this double result, namely, that the *enlightening property* of a luminous surface is, on the one part, proportioned to its extent; and on the other, in the inverse ratio of the squares of the distances.

The consequence of this law is, that the *intensity* of a luminous surface should appear the same, at whatever distance it may be situated, provided that it always subtends a sensible angle.

That this may not, at first, appear contradictory to the very law from which we have deduced it, we will observe that, in the second case, it is the *intensity* of a luminous surface that is spoken of, while in the first it is the *enlightening property* of that surface.

When we wish to compare, not the enlightening property, but the luminous intensity of two surfaces, it is necessary to take equal portions of each, and see

which is the most brilliant. This supposed, we say that, two luminous surfaces being given, if portions of these be viewed, by the eye, through equal openings, thus exposing to sight portions *of the same dimensions*, and these portions appear to have the same intensity, the same will still be true, to whatever distance one of these surfaces may be removed, *provided that the opening through which the part is seen shall always appear full.*

In short; if, on the one hand, each luminous point sends to the eye a number of rays which is in the inverse ratio of the squares of the distances; on the other, the number of luminous points which the eye discovers, *through the same opening*, increases in the same proportion. The intensity of the visible portion of a luminous surface, then, under these circumstances, would not change. The sun, for instance, seen fom Uranus, would appear a circle of one hundred seconds: now, take of the surface of the sun a circle of one hundred seconds, by means of a screen, having a circular hole of this size through it, and we shall have, *in size, and in light*, the sun of Uranus.

Let us now see what use can be made of these principles, in a solution of the question which we have in view, namely, are comets self luminous, or are they not?

Or, the question may be stated thus: in what manner does a comet cease to be visible to us? If its disappearance is an effect of the excessive diminution of its dimensions, and not of the enfeebling of its light, then the comet is self luminous; but if the comet, while it still has great visible dimensions, gradually grows dim, until finally its light is extinguished, such light was doubtless borrowed from the sun, and was only *reflected* by the comet.

All observations, to the present period, appear to prove that this last cause of the disappearance is the

true one, and consequently that comets shine only by reflected light.

This consequence may not, however, be always certain. It is now pretty clearly proved, as we have shown above, that the envelope of comets dilates in proportion as the comet's distance from the sun increases. May it not be, then, that this progressive dilation would produce a gradual diminution of the comet's light? To clear this question, then, of all uncertainty, it will be necessary, hereafter, to consider this cause of the diminution of comets' light, and to demonstrate that it is insufficient to explain the disappearance of these bodies. This complication of the problem will not offer great difficulties.

There are some other questions connected with cometary astronomy, which we now proceed, successively, to examine.

### *Have comets a sensible influence upon the course of the seasons?*

To this question popular prejudices and superstitions have already abundantly responded in the affirmative; but a few words will suffice to dissipate this errour. We will first speak of facts, and let theoretical considerations follow.

Astronomers have sought, by consulting the thermometrical observations which are regularly made, several times each day, at observatories and elsewhere, to determine whether those years which are fruitful in comets have a more elevated temperature than others: the result is, that no sensible difference has been discovered.

This result is precisely that which theoretical data cause us to expect. By what species of agency is it supposed, indeed, that comets can modify our temperature? These bodies cannot act, at a distance, upon

the earth except by attraction, by the emission of luminous or calorifick rays to it, and by the gaseous matter of their tails, which may mingle with our atmosphere.

The attractive force of comets, had it sufficient intensity, would produce tides, analogous to those caused by the attraction of the moon; but no one can see how this could result in an elevation of temperature.

The luminous and calorifick rays which comets emit or reflect to the earth are certainly inadequate to any such result, since they have much less intensity than those which we receive from the moon; and which, concentrated in the focus of the largest lenses, produce no sensible effect, as already shown, when treating of that satellite.

Finally, the introduction, into the terrestrial atmosphere, of a portion of the tails of comets cannot be assigned as a cause of the elevation of temperature which has been erroneously attributed to these bodies, because the tail of the comet of 1811, for example, (which comet was supposed by so many to have caused the abundant crops that followed its appearance,) although it was one hundred millions of miles in length, yet the earth was at all times more than one hundred and fourteen millions of miles distant from the comet and of course far removed from any influence which its tail might be supposed to have exercised upon our atmosphere, had it been mingled with it.

### *Is it possible for a comet to strike the earth, or any of the other planets?*

Comets move in all directions through space, describing ellipses extremely elongated, which traverse our solar system, passing within the orbits of the planets, and consequently, often crossing them. It is not, then, an *impossibility*, that any one of the planets may en-

counter one of these bodies, in its course; and the striking of the earth, therefore, by a comet, is, strictly speaking, possible: but it is, at the same time, exceedingly improbable.

The evidence in support of this proposition will be complete if we compare the small volume of the earth and planets with the immensity of the space in which these bodies move. The mathematical doctrine of probabilities furnishes the means of estimating, numerically, the chances of such a collision; and shows that such chance is as 1 to 280,000,000: that is to say, upon the appearance of an unknown comet, there are 280,000,000 of chances against 1 that it will not strike the earth. From this it is seen how ridiculous it would be for any man, during the few years that he has to pass upon the earth, to occupy himself with dreads and forebodings of such a danger.

On the other hand, the effects of this shock *might* be frightful. If the earth were so struck as that its movement of translation, in its orbit, were destroyed, all bodies and substances which do not adhere firmly to the earth's surface, as animals, the waters, &c. would leave their places and be carried forward with a velocity of about seven leagues per second. If the shock were encountered from a different direction, it would be easy to paint the effects of such a catastrophe. "The axis and the rotary motion of the earth would be changed: the seas would abandon their ancient beds, to precipitate themselves towards the new equator: a great part of both men and animals would be either drowned in this universal deluge, or destroyed by the violent concussion thus produced: entire species would probably be destroyed; and all the monuments of human industry be overturned. Such would be the disasters that the shock of a comet might produce, *if its mass bore any near proportion to that of the earth.*"* This,

* Laplace.

however, from all that is known of comets, is not to be expected; the masses of the observed bodies, of this class, being far too insignificant to cause phenomena like those described.

*Has our globe ever encountered a comet, as the author we have just quoted supposed?*

There have been prominent men who have supposed that the axis of rotation of the earth was not always what it now is. These have supported their opinion upon arguments drawn from the fact that the different degrees measured upon each meridian between the pole and the equator, compared with each other, do not give the same value for the flattening at the poles. They have seen, in the difference of these results, the proof that the earth, at the time when, being still liquid, it assumed its spherical form, did not rotate upon the same axis that it does at present.

But it is easy to see that a change of the axis could not be the cause of the discordances presented by the degrees furnished by observation, with those which result from a certain hypothesis of the flattening; since this disagreement does not observe any gradual and regular progress, but is wholly capricious, and without law. It is, undoubtedly, the result of local attractions, or geological contingencies, which are now known to exist as well in plains as in the vicinity of mountains.

But we pass to other considerations.

If a movement of rotation be impressed upon a spherical, homogeneous body, freely suspended in space, its axis of rotation will remain perpetually invariable. If this body has *any other form* its axis of rotation may change every instant; and this multitude of axes, around each of which it will execute only part of its revolution, are called *instantaneous axes of rotation.* Geometry demonstrates that all bodies, whatever may

be their figure, and the variations of density, in their different parts, will turn constantly and invariably around three axes, perpendicular to each other, and passing through their centre of gravity. These are called the *principal axes of rotation.*

This assumed, for it would be out of place to demonstrate it here, the question arises, namely, is the axis, around which the earth rotates, an *instantaneous* or a *principal* axis? In the first case, the axis changes at each instant, and the equator would be subject, in that event, to corresponding displacements. The terrestrial latitudes, which are only distances measured from the equator, would vary equally with the equator itself. Now, observations upon terrestrial latitude, which are made with extreme exactness, show no change of this kind—these latitudes being found constantly invariable: it is therefore proved that the earth turns round a *principal axis.*

It is easy to draw from this the proof that a comet has never struck the earth; since the effect of such a collision must have been to substitute an *instantaneous axis* for the *principal axis* around which it is proved that the earth rotates: in which case the terrestrial latitudes would now be subject to continual variations—which, as we have seen, is not the case. Indeed it is a bare mathematical *possibility* that the effect of a shock of this kind might be to change the axis from an *instantaneous* to a *principal* one; but this case is so highly improbable that it can scarcely be said to call in question the proof we have given.

What we have said above is based upon the supposition that the earth is an entirely solid body. But its centre may be still liquid; as, indeed, is pretty generally believed, at the present day; although some eminent men refuse their assent to this proposition. Assuming this condition of the earth to be true, the question then arises, can we, in such a case, deduce, with

the same certainty, from the constancy of terrestrial latitudes, the consequence, namely, that the earth has never been struck by a comet?

We think not; for, after the shock, of which the immediate effect would have been to precipitate, with great violence, towards the new equator, a portion of the interiour, liquid mass, which would not be able to assume a position there, without rupturing the solid crust of the earth, the continual displacement of the instantaneous axis causing an incessant transformation of the fluid mass, it is possible that the result of the perpetual friction of this liquid, upon the solid shell, might produce a gradual diminution in the length of the curve described by the extremities of the instantaneous axis, and, consequently, result, at last, in a movement of rotation round a principal axis.

*Can the earth pass into the tail of a comet? and what would be the consequences of such an event to its inhabitants?*

Comets have, in general, very little density; and they therefore can only attract very feebly the matter of which their tails are composed, because, as we have seen, all bodies exercise the force of attraction in proportion to their masses.

Now, without any difficulty, we can conceive that the earth, of which the mass is ordinarily much greater than that of comets, might attract to itself, and mingle with its atmosphere, some portion of the tails of such of these bodies as were favourably situated for such a result; particularly when we recollect at what an immense distance the extremities of these appendages sometimes are from the head of the comets to which they belong.

As to the consequences of the introduction, into our atmosphere, of a new, gaseous element, they must ne-

cessarily depend upon the nature and quantity of the matter: it might, therefore, be destructive of animal life, in whole or in part. But science has not yet registered any event of this kind; and the connexion which many men have sought to establish between the appearance of comets and any of the moral or physical revolutions of the world, has not the slightest foundation in truth, but is the legitimate offspring of credulity and superstition.

*Were the dry fogs of* 1783 *and of* 1831 *caused by portions of matter detached from the tails of comets?*

The fog of 1783 continued one month. It commenced very nearly upon the same day at places greatly distant from each other. It extended from the north of Africa to Sweden. It occupied, also, a great part of North America; but it did not extend over the sea. In its extent upward, it reached above the tops of the highest mountains. It did not appear to be borne along, over the land, by winds; nor did the most abundant rains, or the strongest winds tend to its dispersion. It exhaled a disagreeable odour, was very dry, as shown by the hygroscope, and was possessed of phosphorescent properties.

Such were the facts; and there have been attempts made to explain them by supposing that this fog was the tail of a comet. But if this were so, why is it that no discovery was ever made of the head of the comet to which this tail belonged; for the fog was not such as to obscure the stars? This objection is fundamental, and destroys, entirely, the proposed hypothesis.

The same explanation is still less applicable to the fog of 1831, which offered so great a resemblance to that of 1783; for this fog having covered only a part of Europe, the invisibility of the comet from which the

tail proceeded would be still more surprising. Besides, all the points of the globe comprised between the same parallels of latitude would have been successively covered with this fog, by the effect of the rotation of the earth upon its axis; and yet this fog terminated at fifty leagues from the coast.

A much more satisfactory explanation of the origin of these extraordinary fogs may be found in the interiour revolutions by which our globe is so often agitated. In 1783, the same year of the first of these fogs which we are considering, Calabria was overturned by those terrible earthquakes which destroyed more than 40,000 of the inhabitants; Mount Hecla, in Iceland, sent forth one of the most stupendous eruptions ever known; while new volcanoes rose from the bottom of the sea, &c.

Would it, then, be a difficult thing to suppose that gaseous matter, of an unknown nature, was ejected from the interiour of the earth, while thus torn and agitated by these violent commotions? It certainly would not; and the supposition that such is the explanation is strongly supported by the remarkable circumstance that, over extensive seas, these fogs did not prevail. But we mean no more, here, than barely to indicate one of the hypotheses by the aid of which it would be possible to explain the origin of these dry fogs, without recurring to the immersion of the earth in the tail of a comet.

There exists upon the western coasts of Africa, something very similar to the phenomena that we have described. This is a dry, periodical fog, brought on, or at least occurring at the same time with, a wind known as the *Harmattan*, which causes furniture, in dwellings, to crack; warps the covers of books, as if they had been held against a fire; dries up grass and larger plants; and exercises, upon the human system, an influence no less unpleasant. This fog never ex-

tends much over the sea. Its producing cause is unknown.

*Has the moon ever been struck by a comet?*

We have seen that this satellite turns upon its axis in a time precisely equal to that which it employs to accomplish its revolution round the earth. The equal duration of the periods of these different movements has been thought to be explained by supposing that, at the time the moon, then in a fluid state, was assuming the form which corresponds to its movement of rotation, the attraction of the earth drew the moon into a lengthened form, its major axis being directed towards the centre of the earth.

Now, if a comet had ever struck the moon, the shock would have destroyed the harmony which exists between the movements of rotation and of revolution of this planet, and consequently have caused the major axis of the moon to deviate from a right line to the centre of the earth. In such case, that major axis would execute a series of oscillatory movements, like those of a pendulum, round our earth: but, as nothing of this kind exists, it is considered evidence that a collision between a comet and the moon has never taken place.

*Has the moon been formerly a comet?*

The Arcadians, according to Lucian and Ovid, believed themselves more ancient than the moon. Their ancestors, said they, inhabited the earth before the moon existed. This singular tradition has caused the inquiry to be raised whether the moon was not anciently a comet, which, passing near the earth, was so attracted by that body as to cause it to become its satellite.

There certainly is nothing *impossible* in this; but the considerations which have been offered in support of this opinion, have not the least value. As, upon this hypothesis, the moon, while yet a comet, must have had a very short perihelion distance, the attempt has been made to show, by the burned aspect of some of its mountains, the traces of that enormous heat which it has been supposed it must have experienced, while passing so near the sun. There is a confusion of language in this. It is very true that the appearances of ancient volcanick convulsions give to some points of the surface of the moon a burned appearance; but no appearance there, at the present day, can give any indication of the temperature which the moon may have formerly experienced.

Finally, the partisans of the above opinion will have to explain why the moon has no sensible atmosphere, while all the comets that have been seen have a gaseous envelope surrounding them. If the moon was anciently a comet, what disposition has been made of its envelope?

*Is it possible that the earth shall become the satellite of a comet; and if so, what fate, in such an event, would await its inhabitants?*

That a comet should possess itself of our earth, so as to convert it into a satellite, it is only necessary that the comet have a mass sufficiently considerable, and that it pass sufficiently near the earth. Then it would, without doubt, snatch the earth from the attraction of the sun, and bear it along with itself, as a satellite, in its revolution round that luminary. But the great mass which it is necessary to allow to the comet, and the small distance which can exist between the earth and the comet, in fulfilling these conditions, render this event very slightly probable.

Still, as such an event, speaking rigorously, is possible, let us examine what, in this hypothesis, would be the fate of the inhabitants of the earth. Would our globe, as has often been asserted, experience the extremes of temperature? Would it successively be vitrified, volatilized and congealed? Would it become uninhabitable, and all the animal and vegetable species upon it be destroyed?

Let us suppose, in replying to these questions, that the earth should become the satellite of a comet whose perihelion is very near the sun, and whose aphelion is very distant from it; as the comet of 1680, for example.

This comet completes its revolution in 575 years, describing an ellipse of which the major axis is 138 times greater than the mean distance of the earth from the sun. Its perihelion distance is extremely short. Newton calculated that, at its passage through its perihelion, on the 8th of December, 1680, it experienced a heat 28,000 times greater than that which the earth receives in summer: and which he estimated at 2000 times greater than that of red hot iron.

But this conclusion is by no means admissible. For the solution of the problem which Newton proposed, it is necessary to know the condition of the surface and of the atmosphere of the comet of 1680. Nor is this all: for, suppose our globe placed in the position of that comet, at the time in question, and the problem would not yet be solved. No doubt the earth, at first, would experience a temperature 28,000 times greater than that of summer; but very soon all the liquids which cover its surface would be converted into vapour, producing thick layers of clouds, which would weaken the action of the sun in a proportion that it is impossible to fix, numerically.

Would it be less difficult to determine the temperature of our globe, when it should have accompanied

the comet to its aphelion? In considering only the circumstance of distance, the earth should then be 19,000 times less heated than it now is, in summer; that is to say, as it could not there receive from the sun any appreciable heat, it could only possess that portion of what it imbibed while at its perihelion which had not yet been dissipated: and if it had lost *all this heat*, then it would be of the same temperature as the surrounding space, which, according to the ingenious investigations of Fourier, cannot descend farther than 50° centigrade, equal to 58° of Fahrenheit, below zero.

Now, experiments have proved that man can support a degree of cold of from 49° to 50° centrigrade, below zero, and a heat of 130° above, when he is placed in certain hygrometrical conditions. There is no proof, then, that the human species would be annihilated, by thermometrical influences, if the earth were to become the satellite of a comet; and even of a comet of as great eccentricity of orbit and length of period as that of 1680.

These considerations upon the limits between which the temperatures of the celestial globes may oscillate, are of a nature to render their inhabitation less problematical, in the eyes of such persons as find it difficult to conceive of the existence of beings formed upon a system of organization totally different from our own.

*Was the deluge occasioned by a comet?*

There can exist no doubt, at this day, that our globe has been subjected, in past ages, to great and extensive changes, some of which have evidently been accompanied, if not accomplished, by the violence of powerful agents: nor is there room to doubt that the oceans have changed their beds, so that continents have been alternately submerged and laid bare. To

explain these phenomena, theorists have sought the agency of comets. Let us examine these explanations.

Whiston proposed one which he adapted to all the circumstances of Noah's deluge, as recorded in the book of Genesis. He supposed—and we should here remark that this supposition has nothing inadmissible in it—that the comet of 1680 was in the vicinity of the earth at the time of this deluge. He farthermore supposed the earth to have anciently been a comet, and he believed it composed of a solid nucleus, surrounded by two concentrick orbs, the interiour one constituted of a heavy fluid, and the outer one of water: and still outside of this water he placed the solid crust of the earth, upon which we tread.

This assumed, he placed, at the epoch of the deluge, the comet of 1680 only some three or four thousand leagues from the earth. This body, exercising, by reason of its extreme proximity, a powerful attraction upon the interiour liquids of the earth, produced an immense *tide*, which burst the solid crust composing the earth's surface, and precipitated the liquid mass upon the continents. Such is Whiston's interpretation of *the breaking up of the fountains of the great deep.*

As to the *opening of the windows of Heaven*, as Whiston could not discover such a result in forty days of ordinary rain, which could produce only slight results, he sought this effect in the tail of his comet, which he supposed to have spread through the atmosphere of our globe a sufficient quantity of aqueous vapour to produce the amount of rain spoken of.

This fanciful theory long enjoyed great celebrity, in England, where its author was Professor of Mathematicks, at Cambridge college; but it is almost needless to say that it is now wholly exploded, being unable to sustain a moment's examination.

We shall not speak of the physical constitution which Whiston gave to the earth, and which geology, at this day, in no wise adopts or confirms. We limit ourselves to the remark that his gratuitous suppositions upon the proximity and the mass of the comet of 1680 are insufficient to an explanation of the phenomena.

For instance, the motion of this comet being extremely rapid, its attraction was not exercised sufficiently long upon any one point of the earth to produce the immense *tide* of which we have spoken.

Farthermore, this famous comet passed very near the earth on the 21st of November, 1680; and it is demonstrated that, at the epoch of the deluge, its distance was not less. Yet upon that occasion, namely, 1680, it neither broke up the fountains of the great deep, nor opened the windows of Heaven. Whiston's explanations, then, are inadmissible.

Halley, who embraced this view, though in a more general manner, has endeavoured to explain the presence of marine productions far from any ocean, and even upon the tops of the highest mountains, by supposing the earth to have been struck by a comet.

We have already examined the question, namely, whether the earth has ever been struck by a comet, and shown that it probably has not. We will add, here, that, supposing, for a moment, such to have been the fact, still we seek, in vain, in the effects of such a concussion, any satisfactory explanation of the observed phenomena. The stratification of the marine deposits; the extent and regularity of these formations; their positions; the perfect preservation of the most delicate and fragile shells; and we may add, vegetable leaves and flowers, all exclude the idea of a violent transport of these materials, and demonstrate that they were quietly deposited where we find them.

The explanation of these phenomena no longer presents any difficulty, since science has been enriched

by the accurate and extended views of Mons. *Elie de Beaumont* upon the formation of mountains by the agency of elevating power from beneath; but which, as they belong not to our subject, but to geology, cannot be detailed here.

*Have the different points of our globe suddenly changed their latitude, in consequence of a collision between the earth and a comet?*

We find, in the different climates of Europe, bones of the rhinoceros, the elephant, and other animals, which are not able to live, at the present day, in the latitudes where many of these bones are found. We must, then, suppose, either that the climate of Europe has been considerably lowered, in its temperature, or that, in one of those violent commotions, of which our globe offers some traces, these bones have been transported to higher latitudes, by currents flowing in a northerly direction.

But neither of these hypotheses is in any way adapted to the explanation of the two modern discoveries which have so much occupied the attention of the learned. There was found, in 1771, upon the shore of the Wilhoui, in Siberia, and at several feet beneath the surface of the ground, a rhinoceros in a state of perfect preservation, neither the flesh nor the skin appearing to have undergone any change. Some years since that event, namely, in 1799, there was found, near the mouth of the Lena, upon the shores of the Frozen Ocean, an enormous elephant, enclosed in a mass of frozen mud, and so well preserved that the dogs readily ate its flesh.

How can we explain the presence of these two unwieldly animals in regions so distant from those where we now find them living? Here the agency of the supposed currents is inadmissible, for if these animals

had not been frozen immediately after death, the process of putrefaction would have destroyed them. They have, then, lived in the place where they were found. Then, on the one hand, it has been supposed that Siberia has formerly enjoyed a more elevated temperature than at present, because elephants and rhinoceroses have inhabited there; and, on the other, that the catastrophe in which these animals perished has suddenly rendered this a region of extreme cold.

Now, from these deductions, to the shock of a comet, as their producing cause, is but a single step; for we know no other cause than this which would be capable of producing a sudden change in the latitudes of our globe, accompanied by extreme violence.

The question, then, occurs, is this explanation admissible? We think not.

And, first, is it established that the elephant of Lena, and the rhinoceros of Wilhoui may not have lived under the present climate of Siberia? There is much room to doubt that this has been done; for these animals, otherwise similar, in form and magnitude, to those which at present inhabit Africa and Asia, were distinguished by one circumstance which is particularly worthy of observation, namely, they were covered with a species of fur. The skin of the rhinoceros was thickly studded with bristles, or a species of coarse hair, three or four inches in length; and that of the elephant was covered with a long, black hair, mixed with a thick set coat of reddish wool, while the neck of the animal was furnished with a long mane. These peculiarities are all remarkable, and tend directly to the belief that these animals were fitted, by nature, to inhabit the cold regions of the north.

In addition to this, that celebrated traveller, Humboldt, has recently ascertained that the royal tiger, an animal which we have ever considered as belonging only to the hottest countries, is now a resident of Asia,

in very high latitudes; and that it makes its way, in summer, to the western side of the Altayan mountains. Why, then, could not these elephants, with thick, woolly covering, make their way, during summer, even to Siberia? Supposing them once there, the most ordinary accident, such as a fall, for instance, would be sufficient to envelop them in frozen layers, capable of preserving them from all putrefaction; for, in these latitudes, the entire body of the earth, at a depth of only some twelve or fifteen feet, remains perpetually frozen.

It is not necessary, then, in order to explain the discoveries at Lena and Wilhoui, to recur to the agency of a comet, through its concussion with the earth. On the contrary, this supposition, which we have elsewhere considered inadmissible, can yield us no explanation here. Let us suppose, for instance, that Siberia was formerly near the equator: we must then also admit, that it was, in that position, covered some five leagues deep by water, owing to the rotary motion of the earth; and where, we may ask, were our rhinoceros and our elephant, then? Mons. *Elie de Beaumont* has ingeniously attempted to solve the problem involved by the presence of these animals where they were found, by connecting it with his theory of the formation of mountains. He supposes that the Tian-Chan was elevated in winter, in a country of which the valleys were inhabited by these animals, and the mountains of which being covered with snow, the hot vapours issuing from the earth, at the moment of the volcanick action which upheaved the part in question, dissolved a part of the snows upon the older mountains, producing a vast current of water, at a very low temperature. This current, by bearing along the dead bodies which occurred in its course, would carry them, in about eight days, and without exposing them to putrefaction, to the latitudes of Sibe-

ria, where, of course, they would be at once thoroughly frozen.

*What has caused so widely extended a depression of land, over a great part of Asia? and is this depression to be ascribed to the blow of a comet?*

There is, in Asia, a vast region of some 18,000 square leagues, occupied, in great part, by the Caspian Sea, and where there are many populous towns, which is depressed about 330 feet below the level of the Black Sea, and of the Ocean.

To explain this enormous depression of a great portion of an entire country, recourse has been had, as in so many and so various other cases, to the agency of a comet, which is assumed to have struck the earth in this depressed part.

This explanation was proposed by Halley; but at this day it is wholly abandoned. The earth, as we have seen, has never been struck by a comet; and the geographical phenomenon in question is explicable without resort to this supposition.

It is the generally received opinion of the present day that mountains are formed by the elevation of materials from beneath the surface of the earth, being forced upward, often in a melted state, by volcanick agency. Now the necessary consequence of this must be to produce void spaces, beneath some or all portions of the surrounding surface; and certainly the possibility follows that such surfaces may subsequently sink into the cavities thus formed.

By casting our eyes over the geographical chart we shall see that Asia is more remarkable, for elevated clusters, than any other part of the world, and that around the depressed region of which we have spoken, there rise a series of great mountain chains; the Iran, the Himaleh, the Kuen-Lun, the Thian-Chan, the Caucasus; and the mountains of Armenia, those of Erze-

rum, &c. Now why may not the elevation of these vast masses have caused the depression of the intermediate surface of the globe?

This explanation appears still more plausible, when we add that, in the regions in question, complete stability is not yet arrived at, and that the bottom of the Caspian Sea, for instance, furnishes evidence of alteration, in elevation and depression.

We have seen that comets, in various ages, and among different people, have been objects of the greatest alarm; but we should add that all persons have not yielded to these exciting fears, but have held rational views in regard to these bodies, at times when such views found no favour with the mass of mankind. The period when these views were first entertained, and the people by whom they were originally promulgated, are alike unknown to us. They have, indeed, often been ascribed to Seneca; who said, of comets, that they are the enduring works of nature, and have their appointed route, in which to move; and although they elongate themselves, yet they cease not to exist. They are not confined to the zodiack; but the heavens are free in all their parts, and whereever there is space there may be motion, &c. He also predicted that future ages would make farther discoveries, upon their character, the nature of their orbits, and the periods of their return. Of this famous prediction of Seneca much has been written, claiming, for him, the honour of its first promulgation. But, in rendering to Seneca that justice which is due to him for the *adoption* of these philosophical views, we must not forget that he prophesied, as did the astrologers, namely, after the event. It was from the Chaldeans that Seneca derived his philosophy, upon this subject, and also his famous prediction of the future return of comets; which fact is historically asserted to have been early known to that people.

# CHAPTER TWELFTH.

## OF ECLIPSES.

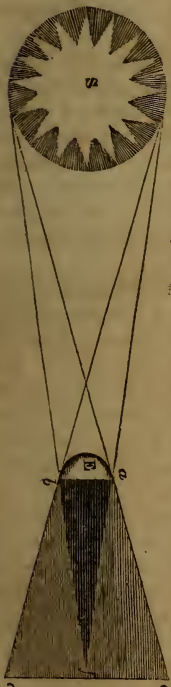
Eclipses, like comets, were of old an object of popular alarm and affright; but at this day there is no one, among civilized nations, but knows that these phenomena are a consequence of the known laws of nature, and that they are predicted, by astronomers, with the same exactness as are the returns of day and night.

### ECLIPSES OF THE MOON.

The earth being a round, opaque body, the sun can only enlighten one half of its surface at any one time; from which it follows that the earth must, at all times project a shadow upon the side opposite to the sun. Let us inquire what is the form of this shadow? and what are its dimensions? If the sun and the earth were of the same magnitude, the shadow would be cylindrical, and of infinite extent; but as the earth is much less than the sun, the shadow which it projects forms a cone sufficiently long to reach the moon, but not so long as to extend to Mars. The length of this conical shadow has been computed at some 300,000 leagues. Upon the sides of this cone are shadows less dark, formed by the interception of a part, only, of the rays of the sun; and of these shadows the intensity decreases in proportion to the increase of distance from the conical shadow. This tint, intermediate between light and perfect shadow, has received the name of *penumbra*. To determine the limits of this partial or imperfect shadow, two lines must be drawn, which, commencing, one at each border of the sun, and *crossing* before they reach the earth, each shall just touch the border of the earth, and be prolonged beyond that planet. The prolongation of these

lines will bound, beyond the earth, a truncated cone, which is that formed by the penumbra. To illustrate this, suppose, fig. 37, S the sun, and E the earth. The cone of the earth's shadow, *a b f*, terminates at *f*, the point where the rays emanating from the borders of the sun meet, after having grazed, as it were, the borders of the earth; while the truncated cone *a b c d* is that formed by the penumbra. This is cut off, or truncated, at its top, so that its width, there, is equal to the diameter of the earth, instead of being a mere point, as in a perfect cone.

Fig. 37.



It is now evident that whenever the earth, in its motion round the sun, occupies a position on a right line, or nearly so, between the sun and the moon, this last body will of necessity be obscured, or eclipsed. This eclipse will be *total* or *partial*, according as the moon is wholly or partially included in the conical shadow, *a b f*, fig. 37, of the earth. The eclipse will be *central*, whenever the centre of the moon coincides exactly with that of the earth's shadow.

If the plane in which the moon moves was not inclined to the ecliptick, this planet would be eclipsed at every full moon; but as the orbit which it describes cuts the ecliptick, in the line of the nodes, it must assume different positions relatively to that plane. If, at opposition, the moon is distant from its nodes, it will pass upon one side or the other of the earth's shadow, without falling into it; which happens in most

cases of opposition: but if the line which joins the centres of the sun, earth and moon, be a right line, or nearly so, which takes place when this last body is in the nodes, or near that position, there must, of necessity, ensue an eclipse.

For the purpose of designating the extent of an eclipse, astronomers suppose the moon divided into twelve equal and parallel zones, called *digits*. Then, when there is one third or one half of the moon eclipsed, we say that it is eclipsed four, or six digits. If the eclipse is total, and the diameter of the shadow is greater than that of the moon, we say that the eclipse is more than twelve digits, and the number of these digits is determined accordingly.

In eclipses of the moon, the place of the spectator makes no difference as to the phenomenon, which must happen at the same instant of absolute time, to all observers, in whatever part of space they are situated; and if the whole eclipse be visible, at all, that is, be above the horizon, it must everywhere have the same magnitude. In the case of the moon it is always upon the *eastern* edge or side of the moon that eclipses of that body commence.

The moon, in approaching the conical shadow of the earth, loses its light by slow and imperceptible degrees, by reason of its entrance into the penumbra, of which we have seen that the intensity augments gradually, from its outer border to the very time of contact with the earth's shadow. When buried in the earth's shadow, the moon does not usually entirely disappear, even when the eclipse is total, because refraction throws some rays of light upon it, within the cone of the earth's shadow. Yet instances have occurred when the disappearance of the moon was complete, owing to clouds in the atmosphere, which interfered with the refraction in question.

We have already said that the eclipses of the moon are visible from all points of the earth which have the moon above the horizon, and that such eclipses have, for all these points, the same extent; but we should add that the hour of the day at which such eclipse will be viewed must vary with the longitude of the spectator, and this circumstance furnishes the means of determining the longitude of those places when accurate observations are made. Eclipses of the moon never exceed four hours, and most of them have a much less duration.

## ECLIPSES OF THE SUN.

When the moon is interposed between the sun and the earth, the sun is eclipsed. The eclipse is *partial*, when the moon only hides a part of the disk of the sun; it is *total* when the entire disk of the sun is hidden; and it is *annular* when the sun, covered by the moon, still shows the border of his disk, for a greater or less width, entirely round the moon, constituting a ring of light outside that body. Lastly, the eclipse is *central* when the observer is situated upon the prolongation of the line which joins the centres of the sun and moon.

The moon being nearly of the same figure as the earth, its shadow and penumbra are found in the same manner; but, as the moon is much less than the earth, the cone of its shadow is never of sufficient magnitude to cover the entire surface of the earth. Eclipses of the sun never take place at the same time throughout the earth; and it is easy to see that an eclipse of this body which shall be total at one place, on the earth, may not be visible at another, although the observer at this last position, should have the sun above the horizon. But, as the moon passes before all the points of the solar disk, it hides this, successively, from

different parts of the earth, in the order of its movement, from west to east. In most solar eclipses the disk of the moon is covered by a pale light which is reflected to it by the enlightened portion of the earth's surface.

The apparent diameter of the moon, when at its maximum, exceeds the minimum diameter of the sun by only 1′ 38″. So that the longest duration of a total, solar eclipse, cannot exceed the time which the moon requires to move over 1′ 38″ of a degree, which is about $7^m$ $58^s$ of time.

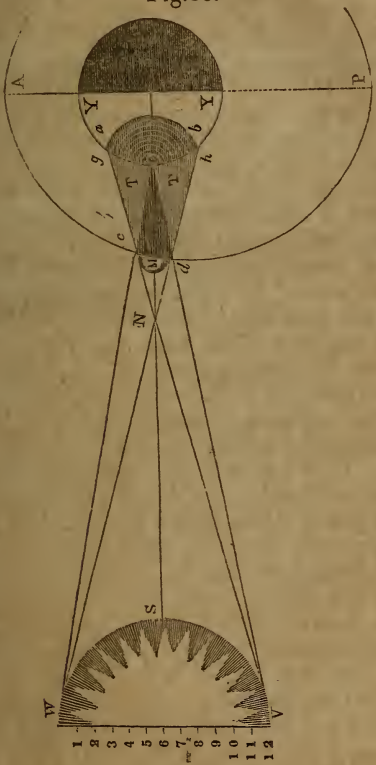
Solar eclipses, like lunar ones, are estimated in digits, by supposing the sun divided into twelve equal parts, also called digits.

We will illustrate, by a diagram, the general phenomena of these eclipses.

Figure 38, suppose S the sun, Y Y the earth, M the moon, and A M P the moon's orbit. If we draw the lines W *c e* and V *d e*, the dark space, *c d e*, comprised between them will be the conical shadow of the moon: the lines W *d h* and V *c g* mark the limits of the penumbra, T T. This assumed, conceive the moon moving in her orbit, from west to east, as from M to P. Now, an observer placed at *b* would see the eastern limb of the moon, *d*, seem to touch the western limb of the sun, W, at the *commencement* of the eclipse, to him. But, at the same instant the western border of the moon, *c*, quits the eastern limb of the sun, at V, which is the *end* of the eclipse to an observer placed at *a*. It is now evident that, in this case, the sun has been eclipsed at all the points between *a* and *b*. But it is also evident, according to the figure, that the sun was not totally eclipsed except for a very small part of the earth at a time, because it is only the extremity of the shadow which reaches the earth. In this diagram the diameter of the sun is seen divided into twelve equal parts, or digits.

The return or repetition of eclipses does not take place, except at considerable intervals of time. They

Fig.38.




can only happen at the syzygies. The synodical revolution of the nodes embraces the period of $346^{d}\ 14^{h}\ 52^{m}\ 16^{s}$; being, to the synodical revolution of the moon, very nearly in the proportion of 223 to 19.

After a period of 223 lunations, then, the sun and moon return to the same position, relatively to the lunar node; and the series of eclipses returns nearly in the same order. The recurrence of eclipses is determined by an observance of this period; and calculation has demonstrated that such return takes place about every 18½ years. This period is thought to be the *Saros* of the Chaldean astronomers; and their predictions of eclipses were probably founded upon it.

As total eclipses of the sun are very rare, some notices of the one which was visible in the United States, on the 16th of June, 1806, may not be uninteresting.

The late distinguished mathematician, Dr. Bowditch, of Boston, observed this eclipse, at Salem, Massachusetts. He says of it: "On the day of the eclipse the weather was remarkably fine, scarcely a cloud being visible in any part of the heavens. Four or five minutes before the commencement of the eclipse I began to observe that part of the sun's limb, where the first contact was expected to take place, and at $10^h\ 8^m\ 28^s$ by the chronometer, I observed the first impression on the limb. In two seconds the indentation of the limb was quite perceptible. As the eclipse advanced there did not appear to be so great a diminution of the light as was generally expected, and it was not till the sun was nearly covered that the darkness was very sensible. A few minutes before this time I recommenced my observations with the telescope, and at $11^h\ 37^m\ 30^s$, by the chronometer, the sun's surface was wholly covered. The last ray of light from the sun's limb disappeared so instantaneously, that it seemed as if there could not have been a mistake of a second in this phase. The whole of the moon was then seen, surrounded by a luminous appearance of considerable extent, such as has generally been taken notice of, in total eclipses of the sun. This light, with a crepuscular brightness round the horizon, prevented the dark-

ness from being great during the time that the sun's surface was wholly covered. The degree of light can be estimated by the number of stars visible to the naked eye. Those I took notice of were *Capella*, *Aldebaran*, *Sirius*, *Procyon*, the three bright stars in the belt of Orion, and the star $\alpha$ in his shoulder. *Venus* and *Mars* were also visible.

"As the time drew near for observing the end of the total darkness, I took notice that there was a visible increase of light, in the atmosphere, for about two seconds before any part of the sun's limb was visible in the telescope; but at $11^h\ 32^m\ 18^s$, by the chronometer, the light burst forth, with great splendour. After this the light appeared to increase much faster than it had decreased, and in a short time it was as light as in a common cloudy day." The whole duration of this eclipse, at Salem, after correcting the chronometers' errour, was $2^h\ 44^m\ 18^s$; and the duration of total darkness, $4^m\ 48^s$.

At Pawlet, Vermont, "the light of the sun instantly ceased for a moment or second of time, and as instantaneously reappeared."

At Tarpaulin Cave, on the coast of Massachusetts, this eclipse was total; while at five miles W. S. W. of this place "the eclipse was not total, but the lucid part of the sun was very small, and of a circular form, and appeared very much agitated; *suddenly changing its place round the south limb of the moon.*"

An observer, at another station, describes the eclipse as "not total, but the sun's limb appeared to be reduced to a small, circular thread, or, rather, like a very fine horn, the upper end of which broke into a drop and instantly disappeared. The lucid part of the sun evidently decreased until $11^h\ 16^m\ 52^s$. The position of the lucid part, at this time seemed to change suddenly to the east, and in a few minutes appeared on that part of the sun where the eclipse began, and the light in-

stantly increased before there was any appearance, to the eye, of an increase of the lucid part."

Such are among the phenomena which scientifick men have recorded of this rare and imposing occurrence.

The author of this observed the same eclipse, from a point near the northern line of Massachusetts. The day was without clouds, and of unusual brightness. The diminution of light, as the obscuration of the sun progressed, was not so rapid as had been anticipated; but the period of total obscuration was one indescribably impressive. The sunless sky appeared, indeed, "the pall of a past world;" and the darkness, though not impenetrable, seemed the sombre precursor of nature's dissolution. A damp chill was every where perceptible, in the open air; and while all men gazed, in mute silence, upon the heavens, domestick fowls and the birds of the grove betook themselves to the perch, while the beasts of the field, suspending every effort, stood motionless with astonishment.

To observations of ancient eclipses, chronology has, in some instances, been greatly indebted for the correction, or the confirmation of its dates. Through the gloom of the palpable night of antiquity, some few rays, from the lights of astronomy, have penetrated; and certainty, amid surrounding chaos, is restored whereever astronomical observations can be recognised. Such facts as can be coupled with these, become fixed points, and serve as asylums for the secure repose of such inquirers as have been led astray by uncertainty, amid the darkness of antiquity. But these observations are rare; and to superstition we must acknowledge ourselves indebted for such as we have. It is, perhaps, singular, that this long night of darkness should be illumined only by such traits as superstition has unintentionally preserved to us. These traits are the phenomena of eclipses, which the terrours of the

people caused them to consecrate to posterity. Whenever we find, in ancient annals, details of occurrences without date or with a false one, but accompanied with a recital of an eclipse, astronomy, supported by a knowledge of the motions of the sun and moon, will immediately, by calculation, ascend into antiquity, and, by examining every eclipse there can have been, will finally identify the one that fell upon the specified day and hour—by which means the date of the event becomes fixed. For the purpose of preserving such researches and calculations, for future practical application, two Benedictine Monks, of the last century, prepared a work which they entitled the Art of verifying Dates; or, of fixing the dates of historical events, by astronomy, through the medium of those eclipses which the ancients have preserved to us.

Among the Chinese, where superstition, in the guise of astrology, is recognised by, and forms part of the administration of national affairs, all ancient chronology is founded upon the observation of eclipses; and it is upon this undeniable evidence, this testimony which admits of no cavil, that, at the epoch of the emperour Yao, more than two thousand years before our era, astronomy was cultivated in China. The calendar, and the announcement of eclipses were important objects, for which a tribunal of mathematicks had been created. They then observed the meridian shadows of the gnomon, at the solstices, and the passages of the stars through the meridian. They also determined the position of the moon, relatively to the stars, at the times of eclipses; and these gave the sidereal positions of the sun and of the solstices.

# CHAPTER THIRTEENTH.

## OF THE TIDES.

The phenomena of the *tides*, which naturally next claim our attention, will receive their explanation in this chapter.

A multitude of theories have, in times past, been presented, upon the cause of these regular and periodick fluctuations of the ocean; and although their relation with the movements of the moon was observed at a very high period of antiquity, yet it was Kepler who first discovered that it was the attraction exercised by that planet which is the producing cause of tides. Newton afterwards showed that this opinion is in harmony with the laws of gravitation; and reasoning from the principles laid down by Kepler, he explained how the tides rise upon two sides of the earth at the same time, one of them being opposite to the moon. This theory of the tides is received, at this day, without dispute, as their true solution.

The waters of the ocean enjoy a degree of mobility, in their particles, which causes them to yield to the slightest impressions, while the ocean and all the great seas are open, and connected with each other: these circumstances contribute greatly to the production of the tides; which are chiefly caused by the combined action of the sun and moon.

We will first consider the action of the moon. It is evident that it is the inequality of the action of this body which chiefly causes the tides; and that these would not exist if the moon acted in a uniform manner over the entire extent of the ocean; in which case the equilibrium of all the parts would be maintained. This equilibrium, then, is disturbed by the action of the moon. Indeed we readily see that its action, being

oblique to those particles of the sea which are in quadrature with it, and direct to those which are situated upon a right line from the moon to the centre of the earth, renders the former heavier, while it lessens the weight of the latter. Under the influence of such action, in order that the equilibrium may be restored, it is necessary that the waters should become elevated, under the moon, in order that the difference in the weight may be compensated by the increased height. The particles of the sea situated in the corresponding point of the opposite hemisphere, being less attracted by the moon than the centre of the earth, by reason of their greater distance from it, will move less rapidly towards that body than will this centre, from which it is evident that high water must take place at this point, nearly at the same instant as under the moon; and that it will be sustained at its elevation by the augmentation of the gravity of the columns of particles situated in quadrature, and freely communicating with the elevated mass.

Fig. 39.

Let us illustrate this by a diagram. Supppose, fig. 39, A B C D E F G H the earth, and M the moon. As attraction acts in the inverse ratio of the squares of the distances, as already shown, the waters situated at Z will be more strongly attracted than those at B and at F, where the oblique force is resolved into two, one acting in the direction of the centre of the earth, O, and the other in a right line to the centre of the moon. The waters at Z, then, it is seen, would become elevated. Meanwhile the centre of the earth, O, being nearer the moon than the waters at N, would be more powerfully attracted than they, and conse-

quently would be drawn more towards that body; or, in other words, would be drawn away from the waters at N, which would remain at an elevation; being sustained, in some degree, too, by the heavier particles at B and F, in quadrature; we say heavier, because, being obliquely attracted by the moon, as we have shown, their gravity is increased. Through the influence of these agencies, then, the waters at B and F, become depressed towards O, while at Z and N they are elevated.

From this it follows that there are formed, upon the surface of the ocean, two meniscus shaped masses of water, one upon the side next the moon, as shown at I Z R, and the other in the opposite hemisphere, at L N K, which give to the watery surface of our globe the form of an oblong spheriod, of which the major axis lies in the right line through the centres of the earth and moon. From what has been shown it is evident that there would be, at any given point, but two tides, or elevations of the water, in each month, were it not for the rotary motion of the earth. Let us now see what complication this rotary motion of the earth adds to the phenomena of the tides.

By the rotary motion of the earth, upon its axis, the most elevated point of the water is removed from directly beneath the moon, in the direction of the rotation; but the water still obeys, for a time, the impulse which the attraction of the moon has given it, and in consequence continues to rise after it has passed from the position directly under the moon, although the immediate attractive action of that body is then, of necessity, diminished. The water never attains its greatest elevation directly under the moon, nor until after the moon has passed the meridian of the place where it occurs. In the open seas, where the waters flow without interruption, the moon is in *p* at the moment of highest water at the points Z and N. It is true, indeed,

that even after the attraction of the moon has ceased its elevating influence, by reason of its having passed out of the meridian of the greatest elevation, the ascending movement, which has been communicated to the water, still continues, for a time; and this, too, even after the moon, from her position, has begun to exert the influence of her attraction somewhat against such ascension.

As before stated, when the moon elevates the waters at Z and at N they are lowered at B and F, since they cannot be elevated at one or more points, without corresponding depressions in others; and reciprocally, when they are elevated at B and F, they are depressed at Z and N, which points will then be in quadrature. But, in consequence of the rotary motion of the earth, the moon passes, each day, through the superiour and inferiour meridian of each point of its surface; thus producing, there, two tides, that is, two elevations and two depressions, in about twenty-four hours.

We have hitherto considered only the action of the moon, in producing the phenomena of the tides; but, as the sun has also an agency in these, we have next to ascertain what this agency is.

The attractive force exercised by the sun, upon the earth, is much superiour to that of the moon; but as the distance of the former of these bodies is nearly four hundred times greater than that of the latter, the attractive power exerted by the one, upon the different parts of our planet acts much nearer in parallel lines, and consequently approaches much nearer to equality upon the whole surface than that of the other. Now, we have seen that it is the attraction of the moon, unequally exercised upon different points of the earth's surface, which causes the tides; and the action of the sun, therefore, which is much more equal upon that surface, must consequently be much less efficient in producing these results. It has been computed that the

influence of the sun is about two and one half times less than that of the moon. Still it is sufficient to produce a flux and reflux of the ocean; so that there are, in fact, *two* tides, one lunar and the other solar; and these act with, or antagonistick to, each other, according to the direction of the forces which produce them. For instance, when the moon is either full or new, that is, when that planet is in the syzygies, A or B,

Fig. 40.

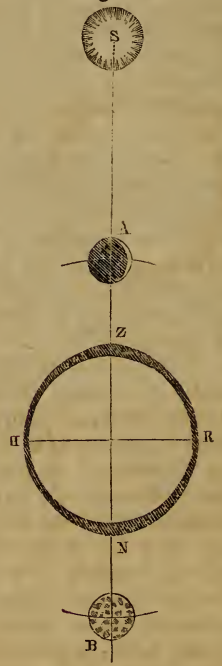
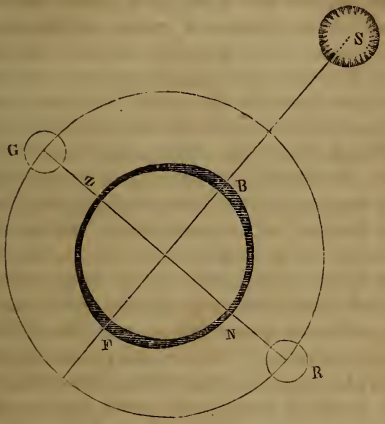



fig. 40. the sun, S, and moon are then in the same meridian, and as their attractive effects are united in

the same line, they should, as in this position they do, produce the greatest possible result—causing the highest tides at Z and N, and the greatest depression at H and R. On the contrary, when the moon is in quadrature, the opposite effect is produced. Suppose, fig. 41,

Fig. 41.




B N F Z the earth, S the sun, G the moon in one part of her orbit, and R the same body in the opposite point, or 180° from G. In either of these positions, the moon being in quadrature, its agency, and that of the sun, in producing tides, are antagonistick to each other; the solar influence tending to produce high water at B and at F, while the lunar attraction tends to produce that result at Z and N. These conflicting forces thus partially destroy each other, and the result is proportionately diminished. Consequently, as the greatest tides known, occur when the sun, moon and earth have the relative positions shown in fig. 40, so the least tides are those which occur when these res-

pective bodies occupy the relative positions assigned them in fig. 41.

It would seem from this that the instant of high tide should be that one when the resultant force of the attractions of the sun and moon has reached its greatest intensity; but we have already seen that this is not so. Upon the days of the new moon, when the sun and moon exert their combined action in the same right line, the instant of the greatest intensity of this action is that of their simultaneous passage of the meridian, or of mid-day: yet the moment of full tide does not ordinarily arrive until sometime after mid-day. Observations and experience have shown that the tide which occurs upon the day of the new moon is that which was produced thirty-six hours previously, by the combined action of the sun and moon: and it has been farther observed that, at this epoch, full tide always occurs at the same hour. From this it has been inferred that the interval of time between the instant of the greatest attraction of the sun and moon, and that of full tide is constantly the same. The second consequence drawn from these two facts is, that the action of the sun and moon is rendered sensible in ports, and upon coasts, by the successive communication of waves and currents.

We have said that, upon the days of new and of full moon, the instant when these two bodies exert the greatest attractive force is that of the passage of the moon through the meridian; and the same is true of the first and last quarter. Upon other days, this instant sometimes precedes and sometimes follows such passage; but it never deviates very greatly, because, as we have seen, the action of the moon is much greater than the sun. These forces, and the retardation or the advance of the tide, upon the time of the moon's passage through the meridian, vary in proportion as the sun and moon recede from or approach to

the earth, as the declinations augment or diminish. The flux of the sea is highest, and the reflux lowest at the time of the equinoxes, in March and September, because at these epochs, all the circumstances tending to the production of tides are so combined as to produce their greatest possible effect.

The following are the principal circumstances of the phenomena of the tides. The waters of the sea run, for about six hours, from south to north, gradually swelling or augmenting their height; they then remain about one quarter of an hour stationary, and then flow from north to south, in the same manner, during the next six hours. After a second repose of fifteen minutes, they again commence to flow north, when the same process is again repeated; and so on, continually.

The period of the flux and reflux is, in mean time, about $12^h\ 25^m$. It is half of the lunar day, which is $24^h\ 50^m$—the time which elapses between two successive returns of the moon to the same point of the meridian. Thus the sea experiences, then, one flux and one reflux, in any given place, as often as the moon passes either the superiour or inferiour meridian of that place; that is to say, twice in $24^h\ 50^m$.

These laws of the flux and reflux of the ocean would perfectly accord with observed phenomena, if the waters of the ocean covered the entire surface of the globe; but this is not the case, and therefore it is only in broad seas, and far from extensive continents, that the phenomena are presented such as we have described them; and there only because the expanse of waters is sufficiently extensive for the sun and the moon to exercise their attractive powers, in giving motion to the waters, without obstruction from contiguous coasts. All these phenomena are necessarily modified, in the vicinity of continents, by the direction of winds, the situation and shape of coasts, inequalities in the depth of water, and various other attendant circumstances.

The tides are very sensibly influential upon the courses of large rivers, often reversing their currents, for great distances; and in some cases the waters of rivers rise, regularly, with every tide, at the distance of two hundred leagues from their mouths; being driven back by the tidal wave of the ocean.

Lakes, or inland seas, are not subject to tides, being too small, in extent of surface, for the action of the moon to become sensible, during the short time which that planet employs in passing over them.

The want of tides in the Mediterranean and Baltick seas is accounted for by the fact that the straits by which these two great lakes communicate with the ocean are so narrow that they cannot receive, through them, in so short a period, a sufficient quantity of water to sensibly elevate their surfaces.

In the West India Islands the tides are comparatively trifling; rarely rising more than from twelve to fifteen inches. This anomaly at first appears the more remarkable, as the regions in question are near the equator, and must, therefore, be subject to a very powerful attraction. But we readily perceive that the waters should not be much elevated, in the vicinity of these islands, the moment we recollect that, the earth turning from west to east, the flux, progressing in a contrary direction, arrives, like an immense wave, and breaks against the coast of America, which arrests it there, and prevents its passing, with the moon, to the Pacifick Ocean. The trade winds, also, which blow constantly from east to west, oppose the reflux, returning from the west.

The same two causes, combined, produce a very remarkable effect in the Gulf of Mexico. The winds and tides continually press the waters into this vast indentation of the coast, until they accumulate there, above the general level, and, by their incessant action, maintain these waters at this increased elevation. Thus

suspended, and unable, by their weight, to overcome the obstacles to their return, these waters flow round the west coast of the island of Cuba, and thence northward, towards the coast of America, forming that remarkable current known as the *Gulf Stream.*

The particles of the atmosphere being endowed, in a still greater degree than those of water, with mobility, and at the same time air being lighter than water, it would seem that this gas should obey the combined action of the sun and moon, and thus experience aerial tides. Yet it has been supposed, in spite of these facts, that proof is furnished that there are no such tides, because the barometer gives us no indication of their existence, by noting the elevations and depressions of the atmosphere. Yet it is easy to see that the barometer could not give us the least indication of such tides, but must remain insensible to them; since the columns of air, however different their height, would remain of the same weight, because the direct effect of a tide is, as we have shown, to maintain the equilibrium by compensating, in height, for the diminution of gravity.

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## CHAPTER FOURTEENTH.

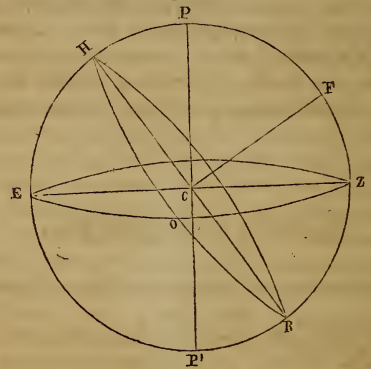
### DETERMINATION OF LATITUDE AND LONGITUDE.

To determine the position of a given point, upon any surface, whatever, it is necessary to know the distance of such point from two fixed lines, upon the same surface. These two lines may be variously disposed; but their situation, upon the surface in question, should be invariably fixed. Yet, by reason of the facilities which it gives both to construction and to computation, such lines are usually disposed so as to form *right* an-

gles with each other, instead of any other angle. It follows, therefore, that the process which we employ to determine the position of different points of the surface of the earth is absolutely the same as that of which we make use to determine the positions of the stars. It is enough if we know the parallel upon which the point in question is situated, and the part of that parallel which it occupies; for, to know these, is to know the latitude and longitude of the place.

And first of *latitude*. This may be determined by simply taking the height of the pole above the horizon; for it is always equal to this height. This has already been shown, in chapter third, pages 73 and 74; but we will repeat the diagram, and, summarily, its description, here. Suppose the point C, fig. 42, is remo-

Fig. 42.




ved 30°, for example, towards the north pole; then, its zenith will be C F; the great circle H O R will be its horizon; the place of the equator, E O Z, will be elongated 30° from the zenith, F, and consequently 60° degrees from the horizon. The pole, P, will be elevated 30°, measured by the angle H C P.

This, then, gives us our latitude: but as there is, in the southern hemisphere, a circle which presents *the same circumstances*, it becomes necessary always to designate whether a given latitude is *north* or *south*. Of course there are as many of these circles, or parallels of latitude, on each side of the equator, as there are points from the equator to the pole.

The determination of *longitude* is attended with much more difficulty. To ascertain this, we measure, in degrees of the equator, the distance which separates the meridian of the place to be determined, from some other known meridian. Now this distance may always be determined, with certainty, provided we know the time at the point where the observation is made, and also the time at the known meridian. The reason for this we will explain. As each point of the earth's surface, by reason of the rotary motion of our globe, upon its axis, describes the circumference of a circle, or 360° in $24^h$, then it, of course, describes 15° in $1^h$, because 15 is the 24th part of 360. Then it follows that, if the two places in question are separated from each other by 15° of longitude, the most western one will not have the sun in its meridian, which is the moment of noon, until one hour after the other. The more eastern of the two, then, will have 12 o'clock, at noon, at the same instant when it is 11 o'clock in the morning at the other place, 15° west of the first. If the distance which separates the two places be 30°, then the difference, for the reasons given, will be two hours, and so on; and for odd degrees, and parts of degrees, in the same proportion—each degree being equivalent to four minutes of time. If the difference of time, then, can be known, at the different points, nothing is easier than to know the difference of longitude: and, reciprocally, if the longitude be known, the time is disclosed by that.

All the difficulty, then, in the case, arises in ascertaining the difference of time. For determining this, a great variety of methods are employed As it is quite impossible for us to make all these known, here, we shall only speak of a few of them.

The exact instants of eclipses of the moon, of the sun, the occultations of stars, by the moon, the eclipses of the satellites of Jupiter, &c. occurring under the known and given meridian, are, to aid the purposes of navigation, &c. carefully calculated and published, several years in advance. Now, suppose a navigator, or traveller upon land, situated at any distance, whatever, to the east, or the west of this given meridian, observes one of these eclipses or occultations, and recurring to his tables of calculations, he there finds the time, at the given meridian, and the difference of this time from that where he is, of course gives him his longitude. He has only to remember that if it is *later* at the place of his observation than at the given meridian, then his longitude is *west*; and if *earlier*, then he is *east* of the given meridian, or in *east* longitude. Whenever the sky is unclouded, we are always enabled to recur to this species of observations, the phenomena, of that kind, being much more numerous than the days of the year: nor is there any necessity, for this purpose, of very powerful instruments; and, indeed, such cannot be employed, at sea, on account of the rolling of the ship.

Marine time pieces, called, also, *chronometers*, are of great assistance in determining longitude. These, from their peculiar construction, and excellant mechanical execution, preserve their uniform rate of motion, with great exactness, in despite of the variations of temperature, and the inevitable jolts and shakings of long voyages. These, on departing upon a voyage, are carefully set to the exact time of that

meridian to which the navigator intends to refer his longitude. By this method he has always at command the means of knowing the difference of time between where he is, and at the assumed meridian; for, while observation gives him that where he is, his chronometer points him to the other; and a comparison of these gives him his longitude.

This last method of resolving the important problem in question is so simple, and so easy of accomplishment, that it would be useless to resort to any other if we were able to depend, with perfect confidence, at all times, upon the exactness of chronometers. But this, unfortunately, cannot always be done. Still, the progress of modern ingenuity has carried the construction of these time pieces to a degree of perfection which, at one time, no person even dared to hope would ever be attained.

Some just idea of this perfection may be formed from the following extract: "If permitted, the author of this work will share with the reader the pleasure and surprise which he experienced, after a long voyage from South America to Asia. The chronometer in his pocket, and those belonging to the ship announced, one morning, that a certain tongue of land, indicated upon the chart, should then be situated fifty miles to the east of the ship. Judge, then, of the excellence of these instruments from the fact that, one hour after, the morning fog having disappeared, the man at the mast head gave the joyful cry of land! land! directly ahead! thus confirming the prediction of the chronometers, within about one mile, after a voyage of such enormous length! It is at such a moment, and under such circumstances, that we are most deeply impressed with profound admiration of human genius. When we compare the dangers of ancient navigation with the safe and confident progress of ships, at

the present day, it is impossible to deny the immense advantages of modern discoveries and ingenuity. If the running of these little instruments had been altered, in the least, during this period of several months, their prediction would have been more injurious than useful; but, by night as by day, in tempest as in calm, in heat and in cold, the beats of these time pieces succeeded each other, with undisturbed uniformity, keeping, if I may so speak, an exact account of the motions both of the heavens and the earth; and, in the midst of the waves of the ocean, which retain no trace, they always marked the exact situation of the ship whose safety had been confided to them, as well as the distance she had run, and the space she had still to overcome, for the completion of her voyage."

We have said that these marine time pieces are to be carefully set to the exact time of that meridian to which the navigator intends to refer his longitude; and that this is to be done at the commencement of his voyage. Now, it will readily occur to the mind that most voyages may commence from ports that are not, themselves, upon this meridian. Such, in fact, is the case: but it will be recollected that if the longitude of any place be known, in degrees, minutes and seconds, it is easy, by converting these into time, to know the hour, minute and second of time upon the first meridian. Then, from whatever port a vessel may commence her voyage, the longitude of that port being previously known—and it is usually recorded in nautical tables—the navigator readily finds the time on his first meridian, by the method we have indicated; and to this time, *and not to that where he is*, he sets his chronometer. The same means are resorted to, so far as practicable, when, from any cause, the time piece shall have become deranged or stopped, upon a voyage: so that there is no necessity of actually

going to the first meridian, as might be supposed, to obtain the true time of that meridian.

The meridian to which each astronomer refers his observations is entirely arbitrary, and differs, with different people. Some of the chief nations assume, as this known meridian, that which passes through their respective capitals: thus French books, maps, charts, &c. have their longitude reckoned from the Royal Observatory, at Paris; the English, in like manner, from Greenwich Observatory, near London; while Americans, *as we have no observatory, in the United States!* are obliged to assume the building known as the Capitol, at Washington.

There are evils attending this multitude of meridians, or starting points, which the celebrated Laplace proposed to remedy, by an agreement, among all nations, to assume some prominent object, in nature, as the Peak of Teneriffe, (one of the Canary Islands) as a common meridian; but unfortunately the suggestion has not been adopted. Indeed Ptolemy, a very ancient astronomer, did assume the most western of the Canary Islands, as his first meridian, this being, in his day, the western limit of known countries; and for a long time his example was followed; but the practice has fallen rapidly into disuse, since the discovery of America, and is now entirely abandoned.

We have spoken of eclipses, occultations, &c., calculated in advance of the time of their occurrence. These are arranged in tables, with a multitude of other no less important calculations, and published in a species of almanack, some three years before their date. This is done in order that every navigator, and every scientifick man, may always be in possession of these, when the day of their use arrives, let him be in what part of the world he may.

One of these works was commenced at Paris, by Picard, in the year 1679, and has been issued, regu-

larly, every year since that time. After this had been published eighty-eight years, namely, in 1767, Maskelyne commenced a similar work, at London, which is still regularly published, every year. There is another of these works, of great merit, and accuracy, published at Berlin. Navigators and others, from the different nations of the continent of Europe, make use of either the Paris or Berlin tables, mostly the former; while the English, of course, employ those of London. These last, being in the language of our own country, are generally, though not wholly, used by navigators of the United States.

There are numerous other astronomical tables, such as tables of each different planet, &c. which it has cost immense labour to calculate, and which have been mostly produced by the French astronomers. These being indispensable, in practice, have been generally copied into the books of the English and other nations.

We have seen, in chapter 9th, page 169, that degrees of latitude, which are measured from the equator towards either pole, are not of equal length; but that, by reason of the flattening of the earth, at the poles, degrees of latitude increase in length, as we approach either pole. But, with degrees of longitude the reverse of this is true. While *latitude* is reckoned upon lines from the equator to the poles, *longitude* is counted, as already shown, upon lines at *right angles* to these, called parallels of latitude. It is evident, from this, that degrees of longitude must vary greatly in their length. The longest is at the equator, being sixty geographical miles; and from this they decrease in length, as the latitude increases, *but not in the same proportion.* That the length of these degrees may readily be known, the following table is given, showing the length, in geographical miles and one hundredth parts of a mile, of every degree of latitude, from the equator to the poles.

TABLE SHOWING THE NUMBER OF MILES AND HUNDREDTHS OF A MILE, IN A DEGREE OF LONGITUDE, IN ANY GIVEN DEGREE OF LATITUDE.

| Degree. | Miles. Dec. | Degree. | Miles. Dec. | Degree. | Miles. Dec. |
|---|---|---|---|---|---|
| 1. | 59 .99 | 31. | 51 .43 | 61. | 29 .09 |
| 2. | 59 .96 | 32. | 50 .88 | 62. | 28 .17 |
| 3. | 59 .92 | 33. | 50 .32 | 63. | 27 .24 |
| 4. | 59 .85 | 34. | 49 .74 | 64. | 26 .30 |
| 5. | 59 .77 | 35. | 49 .15 | 65. | 25 .36 |
| 6. | 59 .67 | 36. | 48 .54 | 66. | 24 .41 |
| 7. | 59 .56 | 37. | 47 .92 | 67. | 23 .44 |
| 8. | 59 .42 | 38. | 47 .28 | 68. | 22 .48 |
| 9. | 59 .26 | 39. | 46 .63 | 69. | 21 .50 |
| 10. | 59 .09 | 40. | 45 .97 | 70. | 20 .52 |
| 11. | 58 .89 | 41. | 45 .28 | 71. | 19 .53 |
| 12. | 58 .69 | 42. | 44 .59 | 72. | 18 .54 |
| 13. | 58 .46 | 43. | 43 .88 | 73. | 17 .54 |
| 14. | 58 .22 | 44. | 43 .16 | 74. | 16 .53 |
| 15. | 57 .95 | 45. | 42 .43 | 75. | 15 .52 |
| 16. | 57 .67 | 46. | 41 .68 | 76. | 14 .51 |
| 17. | 57 .38 | 47. | 40 .92 | 77. | 13 .50 |
| 18. | 57 .06 | 48. | 40 .15 | 78. | 12 .48 |
| 19. | 56 .73 | 49. | 39 .36 | 79. | 11 .45 |
| 20. | 56 .38 | 50. | 38 .57 | 80. | 10 .42 |
| 21. | 56 .02 | 51. | 37 .76 | 81. | 09 .38 |
| 22. | 55 .63 | 52. | 36 .94 | 82. | 08 .35 |
| 23. | 55 .23 | 53. | 36 .11 | 83. | 07 .32 |
| 24. | 54 .81 | 54. | 35 .27 | 84. | 06 .28 |
| 25. | 54 .38 | 55. | 34 .41 | 85. | 05 .24 |
| 26. | 53 .93 | 56. | 33 .55 | 86. | 04 .20 |
| 27. | 53 .46 | 57. | 32 .68 | 87. | 03 .15 |
| 28. | 52 .96 | 58. | 31 .79 | 88. | 02 .10 |
| 29. | 52 .47 | 59. | 30 .90 | 89. | 01 .05 |
| 30. | 51 .96 | 60. | 30 .00 | 90. | 00 .00 |

## CHAPTER FIFTEENTH.

### OF THE ATMOSPHERE, IN ITS ASTRONOMICAL RELATIONS.

The atmosphere is that gaseous envelope which, upon every side, surrounds our globe. Before investigating the influence which this exercises over the observations of astronomical phenomena, let us spend a few minutes in an examination of some of its own properties.

And, first, what is the height of the atmosphere? This question has been resolved by the aid of one of the most precious instruments pertaining to physicks, namely, the *barometer*, an instrument for measuring the weight of the atmosphere. We know that, in carrying the barometer to positions having different degrees of elevation, it should indicate distinct differences in the weight of the column of air above it, at these different elevations; and a simple question of proportion would be sufficient to disclose to us the absolute height of the atmosphere, if it had, throughout all its mass, the same density. But it being extremely compressible, the inferiour layers, next the earth, which have to support the weight of all the superiour layers, are necessarily most compressed, so that the density of an atmospherick column constantly diminishes, from the surface of the earth, upward, to the very surface or limit of the atmosphere itself.

Calculations have shown that, supposing the temperature of the air the same, throughout, the height of the mercurial column, in the barometer, diminishes in arithmetical progression, when the elevations above the level of the sea increase in geometrical progression. But it is necessary, in this experiment, to have strict regard, both to the temperature, and the hygroscopick state of the atmosphere. In this way measures have

been obtained by which it is supposed that the height of the atmosphere is between 30 and 40 miles: its volume one 29th that of the earth, and its weight only forty-three one-thousandths that of our globe.

But what is there beyond the atmosphere? Is there some fluid existing there, or are the planetary spaces an absolute void? We know not, in truth, how this question, *in this particular form*, could so long have occupied the attention of the learned; for really there is nothing of it. How can the celestial spaces be an absolute void, when they are filled with light? Now, whatever opinion we adopt upon the nature of this agent, either that it is a real emanation of the substance of luminous bodies, or a fluid put in motion by these, it is very evident that, upon either hypothesis, the absolute void can have no existence. Void of all *resisting* agents the regions in question may very well be, and probably are.*

But it is particularly in relation to the action which the atmosphere exercises upon the luminous rays which pass through it, that this substance demands our attention, here.

We have seen, at the commencement of this work, the modifications which light experiences in passing out of one medium into another: how it is refracted, and how its rays are decomposed. It is to this property of light that we owe the variegated and party-coloured appearance of the clouds which adorn the horizon at the rising and setting of the sun. It is to this that we are indebted for our preservation, each day, from instantaneous transition from darkness to light, and from light to darkness, through the intervention of morning and evening twilight. These phenomena vary with the diversity of seasons and of place. It has been calculated that, through the effect

* See appendix.

of atmospherick refraction, daylight does not entirely cease, to us, until the sun is 18° below the horizon.

One of the effects of atmospherick refraction is to cause the apparent positions of the stars to vary. In fact, the different layers of the atmosphere, augmenting in density in proportion as they approach the surface of the earth, may be considered, in relation to each other, as different mediums. The luminous rays which traverse these deviate more and more, from a right line, in passing from one to the other; and as the density augments insensibly, this deviation, instead of breaking the rays into a series of right lines, causes them to follow a curved line, *the concavity of which is turned towards the surface of the earth.* It is now easy to conceive how the effect of this refraction is to show us objects *above* their real position: because we always view objects in prolongation of the direction by which the ray of light penetrates the eye, instead of following that ray, in its curvature, through the atmosphere. In this way, refraction augments the apparent heights of the heavenly bodies, when viewed in any direction, except directly in the zenith. Here refraction is nothing; and it augments with every increase of distance from this point to the horizon.

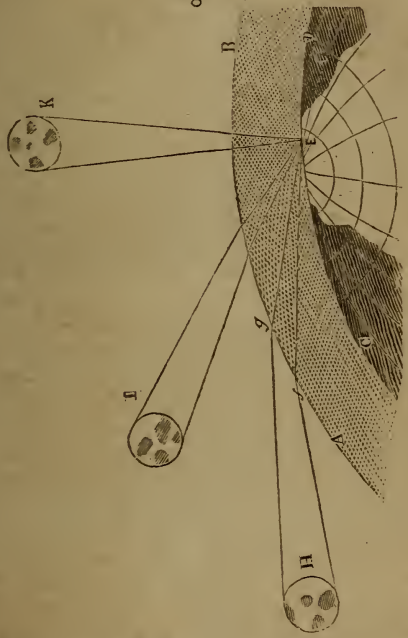
It is proper to explain, here, a phenomenon which the moon presents, at the horizon, and which is sometimes designated the *horizontal moon.* This planet there assumes an elliptical form, and appears much greater, and less brilliant, than when it is in the meridian.

And at first, that we may commence with the circumstances most easily explained, it is evident that if the light of the moon is less vivid at the horizon than in the meridian it is because the luminous rays which it sends to us have to traverse an atmospherick layer

of much greater thickness and density in the former than in the latter position.

To illustrate this, and also the principle of refraction just laid down, suppose, fig. 43, C E D the sur-

Fig. 43.




face of the earth; A B C D the earth's atmosphere; H the moon in the horizon, I the same planet at a greater elevation, and K still the same planet, in the meridian of an observer placed upon the earth, at E. Here it is manifest that the rays from the moon, at H, pass through the greatest distance of atmosphere, and those from K through the least. The refraction, or

bending of the rays from H is seen to be greatest, beginning as they enter the atmosphere, at *f g*, while at K they are not turned from right lines. At H, too, the concave side of the curve followed by the rays is seen to be turned, as before stated, towards the surface of the earth, by which means the spectator, at E, would see the moon in the direction *f g*, while it was really at H. From this diagram it is manifest that the rays from the moon at H must be more feeble and discoloured than from the same body at a greater elevation, particularly when we recollect that these rays pass a long distance near the surface of the earth, and consequently must be obstructed by much vapour.

As to the apparent dimensions of the disk of the moon, it is a phenomenon which has greatly perplexed philosophers. The moon is more distant from us, at the horizon than in the zenith, by half the diameter of the earth—a difference, it is true, so small that it cannot produce, upon the apparent dimensions of this planet, any sensible effect; and most certainly not the effect to enlarge it. What, then, can produce this appearance? Gassendi supposed, as the moon is less brilliant at the horizon than in the meridian, that we enlarge the pupil of the eye more, while looking at it in the former position, and that this would cause it to appear larger. But, in order that this conclusion may be admitted, it is necessary that the enlargement of the pupil of the eye shall augment the size of the image painted upon the retina: which is contrary to all the principles of opticks, and is contradicted by the most exact and careful experiments. Other philosophers have thought, and perhaps with more reason, that the moon appears larger at the horizon than in the meridian, because we suppose it there at a greater distance from us. Indeed they assume that two considerations enter into the act of vision, namely, the angle under which we view the object, and the

distance at which we suppose that object to be situated. This judgement or opinion, which we form unconsciously, directly influences the impression produced by the image; and so true is this result, that we readily appreciate the stature of two men, for instance, who are at very unequal distances from us, and who are therefore seen under very different angles. Another experiment is no less striking. If we place an object upon a horizontal plane, and the eye in the prolongation of that plane, and thus obtain such a view of the object as to see *two* images of it (which is easily done, by pressing the under eyelid and the eye gently upward, with the finger) the two images will be of different magnitudes, *the nearest being the smallest;* and this will continue to decrease, as it is made to approach the eye.

Now, continue the partisans of this explanation, the moon, at the horizon, appears to us to occupy the inferiour part of the immense celestial dome, or vault, and its distance seems to us greater, there, than when at the summit of this dome, that is to say, in the zenith. Again, in the horizon, the moon's apparent distance is still farther increased by those comparisons which intermediate objects furnish. In this way the errour of judgement in regard to distance and its influence modifies the impression produced by the image itself, and causes us to see the moon larger than its size and distance will warrant.

Such is the prevailing explanation of this phenomenon, at the present day. But, without contesting the principles upon which it rests, we think, even if the assigned cause concurs to produce the phenomena of the horizontal moon, that still this is not the sole cause, but that there is another, of which the action and the effects are even more evident; and this is refraction. The luminous rays, emanating from the extreme borders of the moon's disk, through the agency of refrac-

tion, arrive at the eye under a more open angle, thus causing an apparent enlargement of the moon itself.

In regard to the figure which the horizontal moon assumes, this, also, is the effect of refraction. The moon, we have said, in this case assumes an elliptical form. This, by the laws of refraction, should be so; for the rays emanating from the horizontal diameter, penetrating into the atmosphere under the same angle, are equally refracted; while with those which emanate from the vertical diameter, this is not so; for those which come from the upper extremity, entering into the atmosphere in a more oblique direction than those from the inferiour border of the disk, are differently refracted: and the effect of this inequality of refraction should be to change the apparent figure of the moon.

### OF THE HARVEST AND THE HUNTER'S MOONS.

While treating of the moon we will say a few words upon two other phenomena which this planet presents. Twice in each year this planet, when at her full, rises almost at the same time for the period of nearly one week: and it is known at the first of these periods as the *Harvest moon*, and at the other as the *Hunter's moon.*

The moon, as we have seen, moves in its orbit from west to east. When the earth, then, by the effect of its daily revolution upon its axis, returns from one meridian to the same again, the moon, which has in that time passed over a little more than one thirtieth part of her orbit, and in the same direction, is then found to be twelve degrees and some minutes in advance of its position the previous day.

The plane of the equator being perpendicular to the axis of rotation of the earth, it is evident that all the parts of the equinoctial circle make equal angles with

the horizon, both east and west; and that, in equal times, there are always equal portions of this rising and setting, at all times of day, and at every season of the year. If, then, the moon moved always in the equinoctial plane, and if it outran the sun 12° 11′ each day, the distance it moves in its orbit, then this planet would rise and set each day just fifty minutes later than on the preceding day.

But its orbit is considerably inclined to the plane of the equator, and is situated much nearer in the plane of the ecliptick: so near, indeed, that, for the present illustration, we may consider them the same. Now, the different parts of this plane, which is oblique to the axis of the earth, make different angles with the horizon, both east and west. The parts which rise with the least angles are those which set with the greatest, and reciprocally. When this angle is least, then, in equal times, of course, there rises above the horizon a greater portion of the ecliptick than when the angle is greatest. To illustrate this, figs. 44 and

Fig. 44.

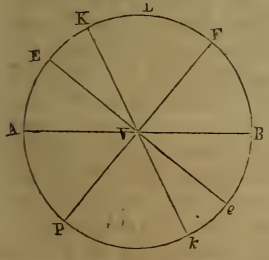
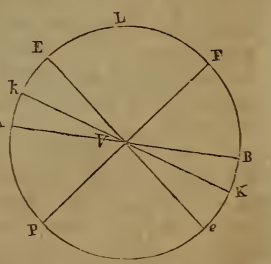



Fig. 45.




45, suppose L the latitude of London, A B the horizon of the place, F P the axis of the world, E *e* the equinoctial, and K *k* the ecliptick. In consequence of the oblique position of the sphere, in the latitude of London, that is, in consequence of its high latitude,

the ecliptick has a high elevation above the horizon, and makes, in fig. 44, the angle A V K, of about sixty-two and a half degrees, when the sign Cancer, ♋, is in the meridian, and that of the Balance, ♎, is just rising in the east. But when the other part of the ecliptick is above the horizon, that is to say, when the sign Capricornus, ♑, is in the meridian, and Aries, ♈, is rising in the east, the ecliptick makes but the very small angle shown at *k* V A, fig. 45, of about 15°, being 47½° less than the former.

Thus, supposing the celestial sphere to turn, as it seems, upon the axis F P, a greater part of the ecliptick will rise above the horizon, in a given time, when the sphere has the position shown in fig. 45, than when it has that shown in fig. 44.

In north latitudes it is when Aries, ♈, is rising and the Balance, ♎, is setting, that the ecliptick makes the smallest angle with the eastern horizon; and it makes the greatest, on the contrary, when the Balance, ♎, is rising, and Aries, ♈, is setting. From the rising of Aries, ♈, to that of the Balance, ♎, a period of twelve sidereal hours, the angle augments; and it decreases during the succeeding half of the sidereal revolution, or from the setting of ♈, to that of ♎. Thus, then, in and near ♈, the ecliptick rises more rapidly above the horizon, while at ♎ its elevation is less rapid.

But in the parallel of London the ecliptick rises as much towards Pisces, ♓, and Aries, ♈, in two hours, as the orbit of the moon in six days; while it is in these signs its risings are retarded only two hours in six days, that is to say, twenty minutes per day, mean time; but the moon, fourteen days after, enters into the Virgin, ♍, and the Balance, ♎, which are opposite to ♓ and ♈; and while it is in these signs its risings, from day to day, are retarded about one hour and fifteen minutes. Through the succeeding signs

Taurus, ♉, Gemini, ♊, Cancer, ♋, Leo, ♌, Virgo, ♍, and Libra, ♎, the angle formed by the ecliptick, with the horizon, augments when they are rising and diminishes when they are setting. Thus the risings of the moon are more and more retarded, while that planet is in these signs, and its settings follow the contrary progression: while the differences of rising grow less and less, through the other six signs, namely, Scorpio, ♏, Sagittarius, ♐, Capricornus, ♑, Aquarius, ♒, Pisces, ♓, and Aries, ♈.

But the moon makes the tour of the ecliptick in $27^d\ 8^h$, and takes $29\frac{1}{2}^d$ to return to the same point; so that it is, during each lunation, in Pisces, ♓, and Aries, ♈, at least once, and sometimes twice.

Each new moon occurs in the same sign, and each full moon in the sign opposite, because, in their interval the moon runs exactly once over the ecliptick. Now, as the full moon rises at the same time that the sun sets, for the reasons that, 1st., when one point of the ecliptick sets the opposite point rises, and 2d., the moon is full only when in the point of the ecliptick opposite to the sun, therefore the moon always rises near the setting of the sun, under the parallel of London, during the week that it is full. But while it elongates itself, in reference to the ecliptick, from conjunction or opposition, the sun passes to the following sign, in $27\frac{1}{2}$ days. The moon, during the same time, surpasses its revolution, and advances more than the sun, during the interval of more than two days, beyond this period, before it can enter into opposition or conjunction again. We see, then, that there cannot be, in any one point of the ecliptick, whatever, more than one conjunction or one opposition. This motion may be compared to that of the hands of a clock, which are never more than once in 12 hours, either in conjunction or opposition in the same part of the dial over which they both move.

Now, as the moon is not full, as we have seen, except when it is in opposition with the sun, and as this last is not in the signs Virgo, ♍, and Libra, ♎, except in autumn, the moon cannot be full, in the opposite signs, namely, Pisces, ♓, and Aries, ♈, except in these two months. There cannot be, then, in any year, more than two full moons which rise, during the period of a week, almost at the same time that the sun sets.

Whenever the moon is in Pisces, ♓, and Aries, ♈, it rises, indeed, almost at the same hour, but this phenomenon passes without notice, if it is not full there. Thus, in winter, these signs rise about mid-day, and the moon being then in quadrature, is not noticed. In the spring the sun and moon are in these signs, and in conjunction, so that the rising of the moon is unobserved. Finally, in summer the rising of the moon, in quadrature, takes place at midnight—a period at which astronomers, alone, would be likely to observe it. It is, then, only in autumn, that the *full* moon, as we have said, rises in these signs, at the setting of the sun; and it is this fact which has attracted so much attention to the phenomenon.

These phenomena are equally regular, in their occurrence, upon one side of the equator as upon the other; but in south latitudes the seasons are the opposite of those at the north. Thus the full moons of spring, upon one side of the equator, are precisely in the signs of the full moons of autumn upon the other side.

Reciprocally, in spring the full moons present, at their setting, the same phenomena which the full moons of autumn exhibit at their rising.

We have supposed, thus far, for the purpose of greater simplicity, that the plane of the lunar orbit coincides with that of the ecliptick; but we know that these two planes make, with each other, an angle of from 5° to 5° 18′, cutting each other in the line of the nodes. Now the moon passes these at least twice, and

often three times in the interval of two changes. Indeed, as the moon gains almost a sign in the interval between two successive changes, if it pass through one node at the epoch of the change, or near it, it will return to this again, after having passed the other, before the succeeding change. Now, while north of the ecliptick, this planet rises earlier and sets later than if moving in the plane of the ecliptick; and while south of that plane, the result is the contrary of this. But the retrograde movement of the nodes causes this difference to vary. For, when the ascending node is in Aries, ♈, the southern half of the moon's orbit makes, with the horizon, an angle of 5½° less than the ecliptick makes with this plane, when Aries, ♈, rises, in northern latitudes: this is why in Pisces, ♓, and Aries, ♈, the moon rises with less variation of time than it would if it moved in the plane of the ecliptick. But the descending node, in its turn, arrives at Aries, ♈, after nine years and 114 days, when the angle which the orbit of the moon makes with the horizon is greater by 151½°, from whence it follows that the moon has longer periods of time, between its risings, in Pisces, ♓, and Aries, ♈, than if it moved in the plane of the ecliptick. Thus it is seen that the phenomena of the Harvest, and the Hunter's moon are not, in all years, equally remarkable; they pass from their maximum to their minimum in the period of nine years and a half.

The full moon of winter is also elevated above the ecliptick, as the sun is in summer; and it should, therefore, remain longer above the horizon; and, reciprocally, in summer its stay is contracted, as the sun's is in winter. It follows from this, that the polar circles, which have the sun 24 hours above the horizon, and 24 hours below this circle, should also have one full moon which should remain 24 hours above, and another 24 hours below the horizon. These two full

moons are the only ones which present these phenomena; all the others both rise and set.

The poles have, as we shall see, in the ensuing chapter, a day of six months, and a night of the same duration, (without regard to the modifications produced by refraction,) upon this distribution of light and darkness. Now, as the full moon, as before stated, is always in opposition to the sun, therefore, when the sun is above the horizon, the moon, at the time of its opposition, or full, is below this plane: it is, then, invisible, half the year. But when the sun has descended below the horizon, the full moons are visible in such places as the sun's rays do not enlighten. Thus the poles, which are deprived of the moon, in summer, that is to say, when they have the sun, have it again enlightening them, in winter, when the sun has sunk below their horizon. They are therefore rarely in great obscurity; since they enjoy so much of the light of the moon, as compensation, in part, for the long absence of the sun.

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## CHAPTER SIXTEENTH.

### OF DAYS AND SEASONS.

We have already seen that if the axis of rotation of the earth was perpendicular to the plane of the ecliptick, the days and nights would have the same duration, in all parts of the earth; but the inclination of these two planes is 23° 28′: and it is this inclination which produces the diversity of seasons, and of days.

It is easy to comprehend the nature and variety which the phenomena of day and night present, upon different points of the earth's surface.

At Paris, for example, the latitude is about 48°. We should have, then, fig. 46, for the zenith, Z O:

H *h* would be the horizon, P *p* the line of the poles, and E *e* the equator. When the sun, S, is in the plane of the equator, it will describe the circle E *e*, which the horizon, H *h*, divides into two equal parts, thus giving the sun an equal time above and below the horizon, and therefore causing the days and nights to be of equal length. But when the sun shall have declined towards the south pole 23° 28′, bringing it to the tropick of Capricorn, ♑, it will describe the circle S′ M; which circle is divided by the horizon, H *h*, into two unequal parts, of which the greater is below this plane; and the nights will consequently be longer than the days. Finally, six months from this time, when the sun shall have attained a northern declination of 23° 28′, which it does on arriving at the tropick of Cancer, ♋, it will describe the circle S″ *n*, which is also divided unequally by the horizon, making the days longer than the nights, at this season.

Fig. 46.

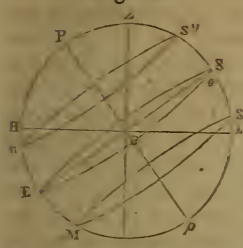
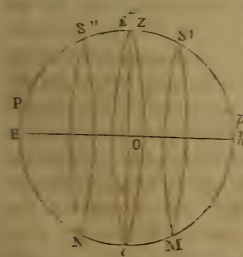


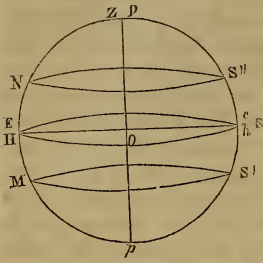

Fig. 47.




Let us now observe the nature of these phenomena in the equatorial regions, represented by fig. 47. To an inhabitant here, the zenith, O Z, coincides with the equatorial plane, E *e*, and the horizon, H *h*, with the axis of the poles, P *p*. Now the sun, whether it be at S, S′, or S″, that is to say, whether it be at the equator or at either tropick, always describes circles which are divided into two equal parts, by the horizon; and consequently

the equatorial regions have always days and nights of equal duration.

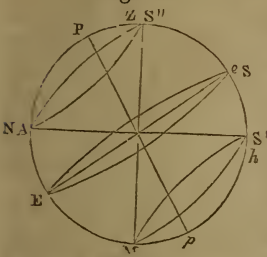
Fig. 48.




The polar regions, on the contrary, fig. 48, have the line of the zenith, O Z, coinciding with that of the poles, P *p*, and their horizon, H *h*, is confounded with the equator, E *e*. When the sun, S, is in the plane of the equator, it describes the circle S H, which is that of the horizon, and one half of the sun's disk, if there were no refraction, would be above, and the other half below this plane. But when the sun, S″, has attained the tropick of Cancer, ☋, it will describe the circle S″ N, which is entirely above the horizon, while at the tropick of Capricorn, ♑, it describes the circle S′ M, which is wholly below the horizon. The polar regions, then, have the sun six months above, and six months below the horizon; that is to say, they have one day and one night, each of six months duration, in a year. However, they are not, during this long absence of the sun, plunged in total darkness: for we have already seen that, independently of the twilight which they enjoy until the sun has descended 18° below the horizon, the moon, during this long absence of the sun, dispenses its light to them. We should add, also, that the twilight must be more intense than elsewhere, by reason of the rapid increase of the density of the air, at moderate heights, in consequence of the almost perpetual congelation of the surface of the earth; and this is one of the causes which has been supposed to produce extraordinary refractions, in these regions.

Finally, at the polar circles, fig. 49, the zenith very nearly coincides with the tropick. When, therefore,

Fig. 49.



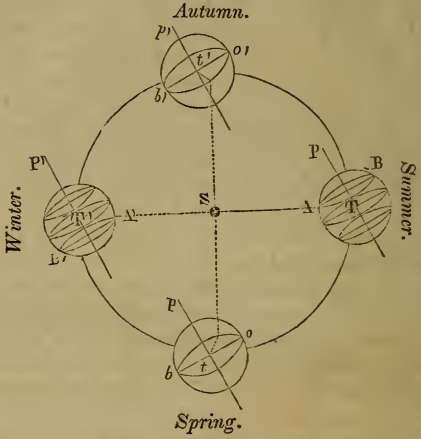

the sun, S, is in the plane of the equator and describes the circle S E, which is divided by the horizon, S′ A, into two equal parts, the days and nights will be of equal length. But when it arrives at the tropick of Cancer, ☋, it will describe the circle S″ N, and will only graze the horizon with its inferiour edge, or border: consequently it would remain above the horizon the whole 24 hours. On the contrary, when the sun arrives at the tropick of Capricorn, ♑, it will describe the circle S′ M, and, of course, remain the whole 24 hours below the horizon, the upper edge of the sun barely rising to the line of the horizon, at one point.

We have supposed, in the foregoing explanations, that the sun moves round the earth, while in fact it is the earth that moves round the sun; but the results are literally the same. Nevertheless, in order to place side by side the apparent and real phenomena, we will now cause the earth to move round the sun, in speaking of the seasons.

Let us suppose, fig. 50, S the sun, T the earth, S T the right line between the centre of the sun and the centre of the earth, in other words the radius vector of the sun and earth. This line touches the surface of the earth at A. All the points, then, of the earth, situated upon the parallel A B, will have the sun succesively in their zenith, as the rotary motion of the earth brings them, one after another, to the position A; and this region then has summer. If the

point A is the solstice of this season, the parallel described by the rotation of the earth, will be the

Fig. 50.




northern tropick, and in this position the plane P T S is perpendicular to that of the ecliptick. But, when the earth, by virtue of its movement of translation, shall have arrived at the point directly opposite, that is to say, at T′, the radius vector will encounter the surface of the earth at A′, and the parallel A′ B′, which, in the preceding position, received the sun's rays most obliquely, will here, in turn, receive them vertically, and the regions thus included now enjoy summer, while those of the opposite tropick have their winter. The plane S T′ P′, formed by the radius vector and the earth's axis, is still perpendicular to the ecliptick, as in the previous case; but the angle, S T P, under which the axis of the earth and the radius vector are joined, in the first position of the figure is acute, that is, it is *less* than a right angle, while that formed by the same lines, in the second

position, S T′ P′, is obtuse, that is, *greater* than a right angle. In the intermediate positions these lines form a right angle: and their angle increases from T to T′, and decreases from T′ to T.

Finally, when the radius vector is perpendicular to the axis of the earth, at the points *t* and *t′*, and when the sun appears to move in the equator, we have then the equinoxes; that is, the days and nights are of equal length throughout the earth; and the season is then either spring or autumn.

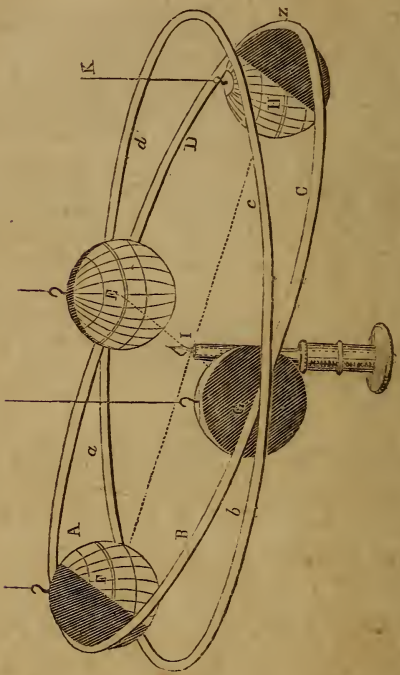
The space comprised between the tropicks has received the name of torrid zone, because, the rays of the sun almost always falling perpendicularly there, the heat is excessive. The regions extending from the tropicks to the polar circles, that is, to two circles $23\frac{1}{2}°$ distant from the two poles, enjoy a more mild climate, and are called the temperate zones. Finally, the regions, almost wholly unknown, which are comprised between the polar circles and the poles, constitute the frigid, or frozen zones.

Any person may readily represent, by a very simple experiment, the two motions of the earth, the one on its axis and the other in its orbit, which, by their combined agency, produce the phenomena of days and seasons.

For this purpose bend a wire into a circle, as represented at *a b c d*, fig. 51. This circle, viewed obliquely, appears elliptical. In the centre place the lighted candle, I: then attach a thread, K, to the pole of a globe that is some two or three inches in diameter. Now, if the thread be so twisted as that, by its untwisting, with the globe suspended by it, it shall cause the globe to turn from west to east, while it is held against the circular wire, the experimenter will see light and shade, or what is the same thing, day and night, succeed each other upon the different parts of the surface of the globe, in regular order, as the

untwisting of the thread gives the globe a rotary motion upon its axis. Then, while the globe thus turns upon

Fig. 51.




its axis, let it be carried, by the thread, along the curved wire, which represents its annual orbit, its centre being always kept on the same level as the wire, and the candle, which, in that case, will always be perpendicular to the equator, will enlighten the globe from pole to pole, and each part of its surface will successively pass through light and darkness, being an

equal time in each. These motions, then, would cause a perpetual equinox; and we should always have days and nights of the same duration, without variation of seasons, if the axis of the earth were perpendicular to its orbit. But this, as before shown, is not so. Let us, then, incline the circle which represents the earth's orbit, so as to give it the position A B C D, for example. Now if we place the globe in the lowest part of this circle, at Z, and while it revolves on its axis, by the untwisting of the thread, we move it along its orbit, that is, the wire, from west to east, the candle will enlighten, perpendicularly, the tropick of Cancer, ☋, and the north pole will be within the enlightened half of the globe. From the equator to the north polar circle, the days will be longer than the nights; while in the southern hemisphere these phenomena will be reversed. But when the movement of translation shall have carried the globe from H towards E, the border of the shadow then approaches the north pole, and of course it has receded, in the same proportion, from the south pole. The parts near the north pole will now be less and less enlightened, while those near the south pole will receive more and more of the sun's rays. The days, then, must decrease, in length, at the north, and increase at the south, in proportion as the globe is carried along from H to E. When it is at E the candle is in the plane of the equator, and the border of the shadow meets that of the enlightened part exactly at each pole, and the days and nights are equal over the whole earth. Finally, when the globe shall have been carried to F and to G, we shall see reproduced, *in an inverted order*, the same phenomena which we have described.

### OF THE TEMPERATURE OF THE EARTH.

The measures made with the micrometer and agreeing with what we otherwise know of the position of

the earth in the ecliptick, at the different seasons of the year, show us that the sun is nearer to the earth, by $\frac{1}{30}$, in winter than in summer. Yet the temperature of summer is much higher than that of winter: and the pupil will therefore very naturally ask, what are the causes of this? There are several, of which we will mention only two. The first is the physical constitution of the atmosphere, which varies materially from one of these seasons to the other. In summer the air is generally dry, but in winter it is much charged with vapours, which considerably enfeeble the intensity of the sun's rays. The other, and which is the principal cause, is, that the sun remains much longer above the horizon in summer than in winter. The night, which is the period of the loss of heat, is shortest in summer, when the day is longest. Some idea may be formed of the effect which the difference in the length of days and nights will produce upon the temperature, when we state that it has been computed that if the sun remained ten hours below the horizon, even in the midst of summer, ice would be formed, at the surface of the earth.

Ordinarily, the temperature, in France, has been considered to rise from the 5th of January to the 5th of July, and to fall from the 5th of July to the 5th of January: but this scale will not, probably, be found strictly applicable to this country.

The mean temperature of the equator is from 27 to 28°. But we must remark that the southern hemisphere is much colder than the northern. The reason of this is that the southern hemisphere is in great part covered by water. Now, we know that water is not as readily heated as the dry land, a great part of the calorick which it receives being constantly absorbed by evaporation, congelation, and the melting of ice.

It has also been observed that the western coasts of continents are much warmer than the eastern: which

is the effect of winds, and of the general position of the seas. In America, no less than in Europe, western winds predominate. Now, these winds, coming from great and open seas, are always temperate; for the temperature of these seas is never either very high or very low, by reason of the mobility of the particles of the liquid mass, and the equilibrium they maintain among themselves; by which particles of water, at the surface, as soon as they become colder than those below, have so augmented in weight, relatively to their size, that they sink down, and warmer particles rise to supply their place.

Has the earth heat properly its own? or is it dependant upon the sun for all it enjoys? These are questions that have engaged much attention. Some philosophers have advanced the latter opinion, namely, that all the heat of the earth is derived from the sun; but they are not sustained, in their position, by the facts in the case. We know that, at a certain depth below the surface, the earth remains constantly at the same temperature, independently of the action of the sun; and experiments have demonstrated that the temperature of the earth increases as we descend farther into it, from the surface. The ratio of this increase, which, indeed, is not every where the same, has been stated at about the average of one degree for every ninety feet.

Whatever may be the cause of this internal increase of the temperature of the earth, whether it arises from original heat, in our globe, as some suppose, or from the incessant action of electrical and calorifick agents, which natural causes are perpetually mingling together, within the earth, as others believe, we are able to demonstrate that this temperature has not changed, at least for several thousand years. Indeed, if the general temperature of our globe had been, at some ancient epoch, either higher or lower than it is at pre-

sent, its volume, by the effect of dilation or contraction, must have been augmented or decreased. Now we know, by the length of the day, and the movements of the moon, that the volume of the earth has not changed, in the least, for the last two thousand years.

We have seen that the temperature increases as we descend into the earth; but it follows the contrary order as we ascend above the level of the sea. In the ordinary state of the atmosphere we find that the temperature decreases equally with the height, if we depart from the same inferiour temperature: but the law of progression changes with this point of departure; so that, in the temperate zones, for example, according to the observations of Saussure, it is, in winter, 755 feet, and in summer, 525 feet, for each degree of the centrigrade thermometer. There is, then, a height where this progressive cooling attains the freezing point; and hence the existence of eternal snows, upon high mountains; and hence, also, the unequal elevation of the points where these snows commence, in different climates. The vertical decrease of temperature varies, also, with the seasons, the exposure of the place, and even the greater or less degree of transparency of the atmosphere.

One of the most curious labours of the present age is the important application which the celebrated Humboldt has made of the geographical positions of plants to the measure of the mean temperature of the positions they occupy. That remarkable traveller has determined, in a general manner, the elevation and temperature of the zones within which each plant seems best to thrive. Each vegetable has its proper and determinate limits of temperature, within which it is alone able to live; and the proximity of these limits is indicated by the stinted and imperfect vegetation found within them. The aspect of the different vegetables which grow in each country, upon its plains,

and upon the sides of its mountains, at different elevations above the level of the sea, afford, then, a species of living thermometer, which indicates to the traveller the mean of the annual temperatures of the limits we have mentioned.

As a general fact we all know that in so vast and moveable a mass as the atmosphere, the slightest causes of agitation may produce the greatest and most lasting commotions. It is easy to see, then, that the slight commotions which we daily witness, in the atmosphere, are the necessary results of local causes, giving rise to variations in temperature; while the greater and more constant agitations of this elastick fluid are as necessarily the effect of the earth's rotary motion, the annual movement of the sun, and the influence, more or less energetick, of the sun upon the earth, and the atmosphere, in the different seasons. Such are, probably, the most ordinary causes of those agitations in the atmosphere which we call *winds*, and which are often of long continuance.

The most remarkable winds are those which blow regularly between the tropicks, and which we call *trade winds*. The following is the explanation which has been given of these.

If the terrestrial globe were in a state of repose, and the sun always emitted its rays constantly upon the same part of its surface, the temperature of the column of atmosphere situated directly over this part, would become highly heated; and all the layers of air in this column would, in succession, one after another, rise to the surface of the atmosphere, like oil to the surface of water, or like smoke and vapour above a focus of strong heat; while currents of air, or *winds*, would move, constantly, from all the inferiour parts of the atmosphere towards this central surface. But the earth is constantly in motion, both upon its axis and round the sun; the whole equatorial zone, there-

fore, may be compared to the surface of which we have spoken, in the hypothesis of the immobility of the earth; for it is there that, from the beginning of time, the sun has constantly poured down its rays: there should be, therefore, as there ever has been, currents of air rushing towards this zone, some from the north and others from the south. Such is the exciting cause of these trade winds; upon the influence of which navigators count with as much assurance as upon the periodick return of the sun, in most positions which are comprised between the thirtieth degree of latitude, north and south.

Yet these winds do not appear to move along the surface of the earth in the direction of the meridians; that is to say, they do not appear to blow directly from north to south, or from south to north, as in fact, they really do. This arises from the rotation of the earth upon its axis; a movement which, taking place from west to east, gives to the winds from the north the appearance of coming from the northeast, and to those from the south a direction from southeast. These appearances may be easily comprehended, by the following facts: when the atmosphere is perfectly calm, if a person on horseback gallop the beast briskly, the wind will seem to blow with violence directly in his face. If he gallop thus toward the east, while the wind blows directly from the north or the south, the two sensations experienced are resolved into one, and in the former case the wind will appear to blow from the northeast, and in the latter, from the southeast. The following example also illustrates the same fact. Cause a globe to revolve briskly upon a vertical axis, and pour upon it, at the superiour pole, water, in a small stream. This water will not instantly acquire the velocity of the globe, but will tend to run down, by the shortest line, to the equator of the globe, or sphere. But the line traced upon the spherical sur-

face will not be a meridian line, as, if the globe were still, it would be, but an oblique one, which, if it were prolonged, would not pass through the inferiour pole. In like manner, it is the rotation of the earth which gives to the trade winds a direction towards the west, and not, as has been sometimes said, the attraction of the sun which gives rise to this phenomenon.

We know that, at the limit or border of the region wherein these winds prevail, that is to say, at about thirty degrees either north or south, computing from the place occupied by the sun, these winds seem to blow almost directly from the east; while in proportion as we approach the central line they strike vessels more directly in a line from north to south, and from south to north. This effect arises from this cause, namely, when the cold air, rushing towards the equator, arrives at the extreme parallels of the region in question, it is heated and dilated before it has acquired a velocity of rotation equal to the zone into which it is just introduced, and it moves, therefore, with less rapidity than that; and bodies situated upon this zone, as ships, men, &c. rush against this air, from west to east, with all the excess of their velocity over that which the air itself has acquired. From this results the same effect as if, the earth being immoveable, the wind from the east blew constantly against these bodies. But, in proportion as these columns of air move forward, they partake, more and more, of the velocity of rotation of the earth, at this part; which velocity they have almost completely acquired when they arrive at the central line of this zone of 60°. Hence it is evident that the eastern direction of these winds becomes less and less sensible, as we approach this line; and, arrived upon it, the western tendency of the winds is scarcely perceptible. Such, very nearly, would be the result from a fluid poured upon a wheel revolving horizontally, and which should advance gra-

dually from the centre towards the circumference. Arrived at points near the limit of this circle, it would not yet have acquired all its velocity; but a continuation of the rotation of the wheel would finally communicate to the liquid all of its own motion. This liquid, then, it will be observed, would have the same velocity as the circumference of the wheel, while it would be in perfect repose, in reference to the surface of that circumference. Of course, we do not include, in this illustration, the effect of centrifugal force.

While the dense air of the polar regions is precipitated towards the equator, to supply the void produced there, in the manner we have shown, thus causing the trade winds, those portions of the atmosphere which the constant action of the sun has dilated and elevated, near the equator, must, of necessity, in the upper regions of the atmosphere, form *counter currents*, and flow off, towards each of the poles, distributing their heat, and contributing to maintain the atmospherick equilibrium. The existence of these phenomena, first foreseen by abstract reasoning, has since been proved by actual observation. It has been found that the summit of the Peak of Teneriffe is constantly exposed to a violent wind, blowing in a contrary direction to that of the trade winds, which raise the waters of the ocean against the base of the mountain. Again, in the year 1812, the volcanick dust and ashes ejected from the island of St. Vincent, passed, in thick clouds, over Barbadoes, to the great astonishment of the inhabitants. This latter island is 55 miles east of St. Vincent; and these ashes, after passing it, fell 50 miles still farther east—being more than one hundred miles, in all, from the crater, whence they issued, and in a direction contrary to the violent winds encountered by vessels navigating the sea about these islands. In passing from the Cape of Good Hope to St. Helena, the light of the sun is often obscured, for several days,

by a mass of thick clouds, which are moving towards the south, at a great height in the air. These clouds are formed of the water which is raised, by evaporation, at the equator, with the heated air, and which has become thus condensed by the cold which it has encountered, in its progress towards the frigid regions of the southern hemisphere.

Out of the tropicks, where the influence of the sun is much less than within them, the winds are occasionally subject to other causes, which, unfortunately for science, are not yet perfectly understood. Winds in the temperate climates, being much less regular, are called *variable;* nevertheless, we may regard as a general rule, and which is equally applicable to both, what has been said of the trade winds, namely, that the air, in moving from the north and south poles, where it was in repose, towards the equatorial regions, must produce the effects of a wind from the east, or a wind in a contrary direction to that of our diurnal motion, until it has acquired, in succession, the velocity of each zone over which it passes; and, reciprocally, that the air, heated in the equatorial regions, and thus raised towards the superiour parts of the atmosphere, where it has acquired very nearly a corresponding velocity, must, in falling towards the poles, with that excess of velocity, from west to east, encounter bodies, at rest upon the earth, as a wind from that direction would do.

These western winds, in many parts, out of the tropicks, are almost as regular as the winds within the tropical zone; and they have, perhaps, an equal claim with the others, to the name of trade winds. These winds abridge the duration of the passage from New York to Liverpool, as compared with the contrary passage, namely, from Liverpool to New York. Thus, then, in the northern hemisphere, a true north wind produces the effect of a northeast wind, and a true

south wind becomes a southwest one. England is exposed to these winds during three hundred days of the year. These phenomena, in the southern hemisphere, occur in the inverted order.

We will terminate this meteorological digression with a notice of two other winds which blow, with regularity, upon coasts, and are known under the names of *land breeze*, and *sea breeze*.

Upon the setting of the sun, each day, both the land and the sea, which its presence has heated, lose their calorick, by radiation; but the loss suffered by the land is much more rapid, and much greater than that of the liquid surface. The layers of air, then, reposing above these two surfaces, must needs become unequally cooled: they do so; and that above the land, being colder and more dense than that over the water, rushes to occupy the position of that which is lighter, over the watery surface. This takes place in the morning, beginning before daylight, and continuing after it, until checked by the heat of the morning sun: it causes a wind from the land toward the sea, which is called the *land breeze*.

But, when the sun is again above the horizon, the influence of his rays is soon felt; and these heat much more rapidly the surface of the soil than the mass of waters. The air, therefore, above the land is, in its turn, more heated and expanded than over the water. Towards the close of the day, therefore, when the inequality of temperature of these layers of atmosphere has become greatest, the more dense layers upon the surface of the ocean are put in motion towards the land, producing the wind called the *sea breeze*.

# CHAPTER SEVENTEENTH.

## OF THE CALENDAR.

A table which indicates the division of time into days, weeks, months, seasons and years, is called a *Calendar.*

The ordinary usages of civil life constantly demand the measure of time. We have no idea of the succession of moments, except what we derive from *motion;* and we can only mark divisions of time by spaces passed over. But, in order that this may be exact, it is necessary that the motion by which we are to recognise the lapse of time, be constant and uniform: and we have no such motion upon the earth. Man has, indeed, in himself, a principle of motion: his sensations and his ideas succeed each other; but with so much irregularity that it is not in his power to measure, with accuracy, the smallest interval of time. The mind which enjoys, and that which suffers acute anguish, count not the same; and time, which hangs heavily, in the days of suffering and grief, flies with the impetuosity of youth, during the gay moments of a joyous and agreeable life. The only constant and uniform motion with which we are conversant is that of the celestial bodies. These move with an unceasing and tranquil pace, through the spaces of the universe. Had they not motion, and had not this motion been observed, we could have no idea, either of age or duration. To man in a solitary or savage state, this knowledge would be of little avail; while it exists, in the social compact, at once the fruit of his industry and the evidence of his dependance.

The interval from one rising of the sun to another, and which we call a day, is a division indicated by nature herself; but society often requires the measure of much longer periods of time, and these have been

determined by making use of the sun and the moon. Indeed, the returns of the same phases of the moon, or of the same seasons, furnish intervals of time which are sensibly equal. All people have united in the use of these methods: some have counted by moons, or months; some by the revolutions of the sun, or years; while others, still, have made promiscuous application of both these methods. All this required, to ensure accuracy, the most exact knowledge of the movements of these bodies; and to those who employed both methods of computation, the farther knowledge of converting either measure into the other, was indispensable. In this way was produced our present calendar, so long notably imperfect, and which, though often reformed, was always so difficult to adjust that it was ever confided, for this purpose, to the hands of the most able and celebrated astronomers.

The opinion of the learned is that one of the years of the Egyptians—for they had several—and that of the Persians, had 365 days; so that every 4 years they lost about one day in the solar year, and after an interval of 1460 years, which was called the great *Canicular Year*, the civil and solar year again commenced at the same time. The 365 days of the year were divided into twelve months, of 30 days each, and the five remaining ones were added, under the name of *complementary days*. It is this calendar which served as the model of that which was established by the French Republick.

The Greeks had a year of 360 days, which they divided into 12 months of 30 days each; and every two years they *intercalated*, or added one month of 30 days, so that they had, alternately, a year of 360, and one of 390 days! In this grossly erroneous way they continued to compute years, until about the sixth century before our era. At this epoch astronomical knowledge had made considerable progress, and from

it men had learned that the moon accomplishes its revolution round the earth in about 29½ days; and by doubling this period they constituted two months, one of 30, and the other of 29 days, commencing at the new moon. But as twelve such months make but 354 days, the 11¼ days which remained were added during a period of eight years, and formed three intercalated months of 30 days, which were added to the third, fifth and eighth years of that period. This method of computation agreed very nearly with the course of the sun; but the Athenians, who made this reformation in the calendar, were apprized, by their oracle, that the year should be regulated by the movement of the sun, and the months and days by that of the moon. The civil year, such as they had now made it, answered very well to this order of the gods; but the second part of the order was not executed. Indeed, after one of these periods, the moon had still one day and a half to accomplish its revolution. After two of these periods, therefore, or sixteen years, they added three complementary days; and this they found to accord very well with the moon, but the accordance with the sun's motion was thereby disturbed.

To resolve this difficulty, a celebrated Greek astronomer, by the name of Meton, who lived about 430 years before our era, invented the *cycle*, or period of 19 years, which very nearly reconciled the movements of the sun and moon, by embracing a complete number of the revolutions of these two bodies. This period consisted of 235 lunations, namely, 228 by reason of the 12 lunations per year, and seven others for the 11¼ days by which each solar year exceeded the lunar one. Of the seven lunar months, six of them had 30 days each, and the 7th was constituted of 29 days. This arrangement met with so much favour with the Greeks that, when it came to be proposed to them, while assembled to celebrate the Olympick

games, it was received with acclamation, and adopted throughout all their dominions. The calculations of this cycle were exposed, in letters of gold, in the publick places, for the use of the citizens; and it is from this circumstance that we have derived the name *golden numbers*, under which they still figure in our calendars. But after all, the cycle of Meton was not perfectly exact; for, after 76 years, it was found to be one day in advance of the course of the moon. This errour was afterwards corrected, by establishing a period of four Metonick cycles, and substracting one day therefrom.

The Arabian calendar, which is that of the Mahometans, is exclusively based upon the course of the moon, and the first day of each month is always that of new moon. The years of this calendar are, of course, very vague; and they retrograde, successively through all the seasons of the year.

We pass to the Roman calendar. Of this we know little, before the time when Julius Cesar reformed it. To accomplish this, having learned, from an Egyptian astronomer, that the solar year is composed of 365 days and ¼, he made the civil year to consist of 365 days, and added one more to every fourth year, to make amends for the quarter which had been neglected. This fourth year, which had 366 days, was called *bissextile*. The months, 12 in number, were of 30 or 31 days, except February, which had but 28 days, except in bissextile years, when one was added, making the number 29. The Romans divided their months into three epochs, namely, the *calends*, which fell upon the first day of the month; the *nones*, which fell upon the 5th, and the *ides*, in like manner, upon the 13th. In the months of March, May, July, and October, the nones fell upon the 7th, and the ides upon the 15th day. The year determined by this calendar was called the *Julian year*.

But this year was too long by $11^m\ 9^s$; an errour which amounted to about a day in 135 years: and the Council of Nice having, in the year 325 of our era, fixed the festival of Easter on the 21st of March, the day of the equinox, in 1582 this festival had receded to the 11th of the same month. To remedy this confusion, Pope Gregory XIII. published a bull or edict, which retrenched ten days of the year 1582; and directed that the day which, by the previous rule of computation, would be the 5th of October, should be assumed as the 15th of that month. But, in order to prevent a recurrence of the same difficulty, a farther modification was necessary. The intercalated day had, to this period, been regularly added to February, every four years: it was now ordered that in the space of 400 years three bissextiles should be retrenched, or omitted; in such a way, that, now, each year whose number is not divisible by 4, has 365 days, while every year divisible by 4, and *not* divisible by 100, has 366; every year divisible by 100 and *not* by 400, has 365 days, and every year divisible by 400 has 366. Thus the year 1600 was bissextile, 1700, 1800, and 1841, were neither of them so, nor will 1900 be; but the year 2000 will be bissextile year. The errour left by this correction is so small that in 10,000 years its accumulated quantity would be less than two days and fifteen hours.

Such is the Gregorian Calendar, or *new style*, as it is sometimes called, which is at present adopted by most Christian countries. But its introduction was not originally effected without some difficulty. As the correction was made under the sanction of a Roman Catholick Pontiff, religious prejudices were immediately enlisted, both for and against the measure. Catholick countries eagerly seized upon its adoption; and in these the new calendar was fully established, within the following year, namely, in 1583. The

Protestant states in Germany resisted the improvement until 1700, when they sanctioned its adoption; but the English obstinately persisted in errour half a century longer. In 1752, however, an act of their Parliament was passed, establishing the Gregorian calendar; and to introduce it, eleven days were struck out, by this act, which provided that the third of September, according to the old style, should be counted the 14th of that month, in the new computation. There are now in Europe only the Russians, and the Christians who adopt the rights of the Greek church, that follow the Julian calendar, of which the year now commences 12 days after ours. This is the cause of the difference which we observe between their dates and those employed by us; or, between old style and new.

Months are divided into weeks. With us the week is of seven days; and these are Sunday, Monday, Tuesday, Wednesday, Thursday, Friday, and Saturday. *Solis*, *Lunæ*, *Martis*, *Mercurii*, *Jovis*, *Veneris*, and *Saturni*, were the days of the Roman week, and also the names of the seven planets. So with us, Saturday, Sunday and Monday clearly denote Saturn's day, the Sun's day, and the Moon's day; and Tuesday, Wednesday, Thursday and Friday, are the days of *Tuisco*, *Woden*, *Thor*, and *Friga*, which are the Saxton names for Mars, Mercury, Jupiter, and Venus. So the French have *Lundi*, the Moon's day, *Mardi*, Mars' day, *Mercredi*, Mercury's day, *Jeudi*, Jupiter's day, *Vendredi*, Venus' day, *Samedi*, Saturn's day, and *Dimanche*, the Sun's day. But what we should not have discovered, had not the historians informed us of it, is the order in which these planets gave their names to the days of the week. The ancients classed the planets, or rather those bodies which they considered such, according to the duration of their revolutions; thus, Saturn, Jupiter, Mars, the Sun, Venus, Mercury and the Moon. Now these planets, thus ar-

ranged, have given their names to the days of the week in the order in which we now employ them. Thus, the first hour of Saturday, for instance, was consecrated to Saturn, and for this reason, gave its name to the day. The second hour was consecrated to Jupiter, the 3d to Mars, the 4th to the Sun, the 5th to Venus, the 6th to Mercury, and the 7th to the Moon; then the 8th to Saturn, again, and so on to the 24th hour, which, by following the calculation through, will be found consecrated to Mars. The first hour of the following day, then, is consecrated to the next in order, which is the Sun, and the day consequently takes his name; the second hour being consecrated to Venus, and so on through the whole. By pursuing this calculation, we see that each day of the week comes thus, in its turn, to receive its name from the planet to which its first hour was consecrated.

It remains for us to say a few words upon some terms employed in our calendars.

The *solar cycle* is a period of 28 years, after which the days of the week return, in the same order, and on the same day of the month, while the bissextiles succeed each other, regularly every four years. The bissextile years, also, at the expiration of the solar cycle, recommence the same course, in regard to the days of the week upon which those of the months fall. The solar cycle owes its origin to the fact that the year does not contain an exact number of weeks, since it has fifty-two weeks and one day. This cycle, then, would be of only seven years, (because, after this time, the one odd day of each year would amount to a week,) if there were no bissextile years; but as there is one of these every four years, for the most part, (though not always,) the cycle must embrace such a number of years as to include seven of these, in order that the day added to each one of them, may constitute a week.

We have already spoken of the cycle of the moon, and of the *golden numbers.* This cycle is a period of nineteen years; after which the sun and the moon return to the same relative positions, or very nearly; for the conjunctions, oppositions, &c. of these bodies are, within about an hour and a half, the same as at the commencement of the period, on the same days of the months.

It is not until after nineteen years that the solar and lunar years again commence together; and the reason of this is, that there is, in the interval, an excess in the former over the latter. The number of days by which the solar exceeds the lunar year, in this case, is what we designate *epact*, in our calendars.

## EQUATION OF TIME.

In all our calendars there are always to be found statements of the quantity of *disagreement* between our clocks and the sun, differing with the varying seasons of the year. We have already seen that the earth does not move in a circle, but in an ellipse, and that the sun occupies one of its foci: from which it has been shown that the earth does not move with the same velocity in all parts of its orbit, or during the whole year. It has also been shown that the sun does not move in the celestial equator, which would be the case if the planes of the equator and the ecliptick coincided. Did they so, then equal portions of the earth's equator would pass through the meridian of the sun in equal times, and so of the rest of the earth's surface; but by reason of the inclination of the ecliptick, as already shown, given portions of this, the sun's apparent path, do not correspond with equal portions of the equator.

These two causes, combined, produce a difference in the length of the *natural* or *solar* days, at different

periods of the year; about one half of these days being a fraction more than twenty-four hours long, and about one half a corresponding fraction less. This gives rise to two species of time, namely, *apparent* time, or that indicated by the shadow of the sun, upon a dial; and *mean* time, or that measured by a well regulated clock. The difference between these is called the *equation.* It is mean time that our clocks and watches are intended to keep; that is, they mark days and hours of equal or equated length, throughout the year. Now, when the natural day is *more* than twenty-four hours long it will, of course, be noon by the clock before it is noon by the sun, and then we say the sun is *slow of the clock.* on the other hand, when the natural day is *less* than twenty-four hours long, then it will not be noon by the clock until after it is so by the sun; and in this case we say the sun is *fast of the clock.* At those periods of the year when the natural day is just twenty-four hours long, there is perfect agreement in the time denoted by the sundial, and that by the clock.

The following is a table of the days of the mean year upon which a well regulated clock will be *fast* or *slow*, with reference to the sun, by the quantity of one or more entire minutes, at solar mid-day, or noon.

FAST OF THE CLOCK IS INDICATED BY F, AND SLOW OF THE CLOCK BY S.

| Month and Day. | Minutes. | Month and Day. | Minutes. | Month and Day. | Minutes. |
|---|---|---|---|---|---|
| January. | F. | May. | S. | September. | S. |
| 2 | 4 | 1 | 3 | 27 | 9 |
| 4 | 5 | 15 | 4 | 30 | 10 |
| 6 | 6 | 30 | 3 | October. | |
| 8 | 7 | June. | | 4 | 11 |
| 11 | 8 | 5 | 2 | 7 | 12 |
| 13 | 9 | 11 | 1 | 11 | 13 |
| 16 | 10 | 16 | 0 | 15 | 14 |
| 19 | 11 | | F. | 20 | 15 |
| 22 | 12 | 20 | 1 | 28 | 16 |
| 27 | 13 | 25 | 2 | November. | |
| February. | | 30 | 3 | 16 | 15 |
| 1 | 14 | July. | | 21 | 14 |
| 21 | 14 | 5 | 4 | 25 | 13 |
| 28 | 13 | 11 | 5 | 28 | 12 |
| March. | | 22 | 6 | December. | |
| 5 | 12 | August. | | 1 | 11 |
| 9 | 11 | 11 | 5 | 3 | 10 |
| 12 | 10 | 16 | 4 | 6 | 9 |
| 16 | 9 | 21 | 3 | 8 | 8 |
| 19 | 8 | 25 | 2 | 10 | 7 |
| 23 | 7 | 29 | 1 | 12 | 6 |
| 26 | 6 | September. | | 14 | 5 |
| 29 | 5 | 1 | 0 | 17 | 4 |
| April. | | | S. | 19 | 3 |
| 1 | 4 | 4 | 1 | 21 | 2 |
| 5 | 3 | 7 | 2 | 23 | 1 |
| 8 | 2 | 10 | 3 | 25 | 0 |
| 12 | 1 | 13 | 4 | | F. |
| 16 | 0 | 16 | 5 | 27 | 1 |
| | S. | 19 | 6 | 29 | 2 |
| 20 | 1 | 22 | 7 | 30 | 3 |
| 25 | 2 | 24 | 8 | | |

# APPENDIX.

The following "examination," &c. was originally prepared for Silliman's *Journal of Science;* in which work it appeared, in 1838.

As the mass of facts here assembled, upon the subject under examination, and some others, collateral thereto, are nowhere else to be met with, in a collected form, and nevertheless are such as may be supposed of some interest to inquirers in Astronomy, yet, as the style and manner of their presentation, here, are both unsuited to the more elementary form of the foregoing pages, it is manifest that, in their present form, their incorporation there would have been impolitick, because detrimental. The essay, therefore, is added in the form of an *Appendix;* thus excluding it from the elementary exercises of the pupil, while placing it within the reach of any and of all who may wish to pursue the subject of which it treats beyond the point at which it has been deemed advisable to dismiss its discussion, in the body of this work.

# APPENDIX.

## EXAMINATION OF THE THEORY OF A RESISTING MEDIUM, IN WHICH IT IS ASSUMED THAT THE PLANETS AND COMETS OF OUR SYSTEM ARE MOVED.

In all ages, when astronomy has been cultivated, the opinion seems to have been entertained, in some one or more of its numerous forms and modifications, that the regions around us, beyond our atmosphere, and to an indefinite extent, are supplied with a rare, invisible medium, of unknown composition and character, in which all the bodies of our solar system, and perhaps the bodies of all other systems also, in executing the several motions assigned them, are necessitated to move. To this substance the name of *ether* has usually been applied; and by this name we propose to designate it, while we examine into its history, the evidences of its existence, and its effects. The period at which this celestial ether was introduced into the science of astronomy, no less than the race of people by whom it was effected, is probably beyond the reach of inquiry: we know only that in the most remote periods of the history of that science, we find it constituting a prominent part of the celestial mechanism. The Bramins, of India, whose astronomical tables are still preserved to us, assumed its existence, and figuratively

supposed the stars to move themselves therein, in a manner similar to the movement of fish in water. The name by which it was known to them is *akash;* and Mr. Dow, in his dissertation upon the religion of the Bramins, defines it to be "a celestial element, pure and impalpable, in which the planets move." "This element," he continues, according to Bedang, offers no resistance; so that the planets have moved uninterruptedly therein, from their first impulsion which they received from the hand of Brama; and they will not be arrested until the moment when he shall seize them in the midst of their course." The Chaldeans, also, held this opinion, and in the figurative language of the East were wont to represent the planets, including the sun, the earth and the moon, as vessels moving therein, and suited to such navigation. Alhazen, an Arabian optician of the eleventh century, taught the existence of ether, which he designated "the substance of heaven," and he supposed it situated beyond, and differing in character from, our atmosphere. Tycho Brahe reinstated the ether of the ancients in all its rights. But though he regarded it as existent, he denied to it the power of causing refraction, which he attributed solely to the grosser vapours of our atmosphere. Whatever may be the difference in the natures of these two fluids, says he, the atmosphere so diminishes in density upward, that at the point where it touches the ether it differs little from it. Kepler, in following the crowd who had gone before him, revived this theory, in his day, and turned the substance in question to good account in framing some of the absurd theories which he put forth, along with his immortal discoveries. In seeking the origin of comets, he supposed them native inhabitants of this ether, as fishes are of the waters of the earth; and that God created them to inhabit the immense spaces of the universe, as he did whales and other monsters to people the vast solitudes of the ocean.

The sombre and bloody appearance which the sun sometimes exhibits he attributed to a coagulation of the ether; and when these appearances ceased, that result was produced by a collection of the grosser portions, which had distributed its transparency, and their conversion into comets.

Through the long period of time embraced by these references, we see the existence of this fluid matter every where accredited; yet so vague and indefinite do all ideas respecting it appear to have been, that rigid investigation of its character or necessity seems to have been quite neglected; and even its practical utility, so far as we know, was but very limitedly considered. But we are now to enter upon a new era, and that a very important one, in the history of this fluid; for we are to see it elevated from the subordinate station hitherto assigned it, to that of a primary agent in carrying out the great motions of the universe. This application was the offspring of the genius of DESCARTES. The conception was a sublime one which dared to identify the law of the general movement of the universe, with that of the movement of terrestrial bodies: and this is due to Descartes. His vortices are a bad explanation of gravity and of the system of the world, but they are mechanical. He discovered that the same mechanism moved bodies in the celestial spaces and at the surface of the earth; and if he was not able to seize this mechanism, we should not forget that this new and sublime thought was of his conception. According to this philosopher "matter, possessed only of the properties of extension, impenetrability and inertia, was supposed to fill all space, and its parts, both great and small, to be endued with motion in an infinite variety of directions. From the combination of these, the rectilineal motion of the parts became impossible; the atoms or particles of matter were continually diverted from the lines in which they had begun to

move; so that circular motion and centrifugal force originated from their action on one another. Thus matter came to be formed into a multitude of vortices, differing in extent, in velocity and density; the more subtile parts constituting the real vortex, in which the denser bodies float, and by which they are pressed, though not equally, on all sides. Thus the universe consists of a multitude of vortices, which limit and circumscribe one another. The earth and the planets are bodies carried round in the great vortex of the solar system; and by the pressure of the subtile matter, which circulates with great rapidity, and great centrifugal force, the denser bodies, which have less rapidity, and less centrifugal force, are forced down toward the sun, the centre of the vortex. In like manner, each planet is itself the centre of a smaller vortex, by the subtile matter of which the phenomena of gravity are produced, just as with us at the surface of the earth." In this system of philosophy, if such it may be called, the agency of the ether, in causing and sustaining the planetary motions, is indispensable; and when we consider how universal was the belief, by all learned and scientifick men, in this doctrine, for more than half a century, we find a ready excuse for the opinion of the less informed upon the subject. For more than thirty years after the publication of Newton's discoveries, this absurd doctrine of vortices kept its ground in France, Germany, and in the universities of England and Scotland. It was finally driven out of the Cambridge University, in England, by a friend of Newton's publishing, in 1718, an edition of their Cartesian text book, *with notes*, embracing the truths which Newton had disclosed. These gradually undermined the doctrine of Descartes, and finally caused its expulsion. This, however, was a work of time; and the absurdities in question were not generally, or even in any considerable degree, driven from the colleges and

learned societies of Europe, before about the year 1720*.

When the errours of Descartes were finally removed from the schools, and from the minds of philosophers, they gave place to the Copernican system of the universe, as rigidly demonstrated by Newton, upon the basis of the laws of Kepler. By this system, and these demonstrations, the celestial revolutions are shown to be carried on independently of all assistance from the ether; and the agency of that fluid was consequently no longer demanded. But, though thus discarded from all participation in planetary motion, a belief in the existence of this fluid was still retained by Newton, who sought to employ it in a new capacity. "And now we might add something concerning a certain most subtile spirit, which pervades and lies hid in all gross bodies; by the force and action of which spirit, the particles of bodies mutually attract one another at near distances, and cohere if contiguous; and electrick bodies operate to greater distances, as well repelling as attracting the neighbouring corpuscles; and light is emitted, reflected, refracted, inflected, and heats bodies." He furthermore

* It is, then, no more than about one hundred and twenty years since even the learned world became sane upon the grand outline, alone, of the celestial mechanism. Three of the colleges of our own country were founded prior to that date, namely, Harvard, in 1638; William and Mary, in 1693; and Yale, in 1700. At that early period of our history, and with the professors' chairs, in these institutions, generally occupied by European scholars, we can hardly suppose wide deviations, in the doctrines taught, from the received opinions in Europe; and consequently, without any direct proof at hand, upon this point, we from necessity infer that the New World has just claims to a portion of whatever of renown or reproach may rightfully attach to the inculcation of the Cartesian doctrine of the universe, at so late a day; and that, for a period of eighty years, this was gravely taught and believed, at one, and for shorter periods at two other of the colleges of our infant country.

supposed that this substance is spread through all the heavens; and when for lack of demonstration, uncertainty arose in his mind, he thus queried: "Is not this medium much rarer within the dense bodies of the sun, stars, planets and comets, than in the empty, celestial spaces between them? And in passing from them to great distances, doth it not grow denser and denser perpetually, and thereby cause the gravity of those great bodies towards one another, and of their parts towards the bodies; every body endeavouring to go from the denser parts of the medium towards the rarer?"

In 1762 the Academy of Sciences, of Paris, proposed, for a prize, the question, "*Do the planets revolve in a medium of which the resistance produces a sensible effect upon their movements?*" For this prize M. l'abbé Bossut was the successful competitor. His calculations showed him that the effect of resistance, offered to the planets, would be to diminish the axis of their orbits, and consequently to shorten their periods of revolution. An acceleration in the movements of the moon had been observed, which was without explanation, and on applying his reasonings to the motions of this planet he satisfied himself that the observed acceleration was due to the resistance of ether, encountered by the moon, in traversing her orbit. The sum of that resistance he measured; and this theory being equally applicable to all the planets, he extended it to them all, and subjected each to the resisting influence of the ether.

The tails of comets were objects of early attention; and it was remarked, both by *Fracastor* and *Apian*, that the tail of the comet of 1531, and those of two subsequent ones, *were all directed opposite to the sun.* Pingré subsequently supposed that these tails are formed of the most subtile portions of the comet's atmosphere, greatly rarefied by the sun, and driven

to the side *opposite the sun*, by the resistance of the ether; aided, perhaps, by the solar rays. This direction of comets' tails, as laid down by Fracastor and Apian, seems to have been very universally adopted. *Newton* says the tails of comets arise from their heads, and tend towards the parts opposite to the sun. *Bailly* adopts the same opinion, in strong language, namely, that the tails are always opposite the sun. *Delambre* is equally unreserved. He says the tail of a comet is always opposite the sun, or in prolongation of the radius vector of the sun and the comet. *Laplace* calls them trains of vapour, always situated on the other side of the heads of comets, relatively to the sun. *Vince* says comets are surrounded by a dense atmosphere, and from the side opposite the sun they send forth a tail. *Bonnycastle* denominates them fiery tails, which continually issue from that side of the comets which is farthest from the sun. *Brewster* states that when a comet is near its perihelion, it is accompanied with a tail or train of light, directly opposite the sun. *Morse* avows that comets are usually attended with a long train of light, always opposite to the sun. *Prof. Farrar*, of Harvard, describes the trains, and adds, their direction is always opposite to the sun. The younger *Herschel* describes the nucleus, and adds that from the head, and in a direction *opposite to that in which the sun is situated* from the comet, appear to diverge two streams of light, constituting the tail. Sustained by the high standing and great numerical force of these authorities, the position here assumed has quite regularly found credence and a place in the numerous works of subordinate authors; insomuch that we have pretty uniformly recognised it in the elementary works upon astronomy that we have examined in the English language.

The cause assigned for this direction of comets' trains, by Pingré, namely, the resistance of the ether,

appears not to have found much favour in the minds of his successors; consequently we find, in general, the expression employed, namely, "*impulsion of the sun's rays*," to denote both the agent and the manner of that agent's action, in producing this result.

Great additional impulse has, within a few years, been given to the theory of a resisting medium by the detailed and able paper of Prof. Encke, upon the observed decrease of the times of revolution of the comet which bears the name of that astronomer. This paper has been translated into English, and is more or less extensively quoted by almost every writer who has employed his pen upon celestial motions, since the date of its appearance. The author says: "If I may be permitted to express my opinion on a subject which, for twelve years, has incessantly occupied me, in treating which I have avoided no method, however circuitous, no kind of verification, in order to reach the truth, as far as it lay in my power; I cannot consider it otherwise than completely established, that an extraordinary correction is necessary for Pons' [Encke's] comet, and equally certain that the principal part of it consists in an increase of the mean motion proportionate to the time." Dr. Bowditch, by reference to the memoir of Encke, supposes the existence of a resisting medium highly probable, as there disclosed, in the motions of Encke's comet, in its successive appearances between the years 1786, and 1829. Arago, of the Royal Observatory, at Paris, in an essay, in 1832, fully recognises this resisting medium, on the authority of Encke, and dwells at considerable length upon its effects. Mons. Gautier assumes that, results obtained in 1828, from the movement of Encke's comet, accord with those which Encke had previously procured, and which induced him, (Encke,) in 1823 to suppose the existence of a medium or etherial fluid, in space, of which the

resistance, acting as a tangential force against the motion of the comet, would augment the power of the sun, and shorten the period of revolution. The younger Herschel refers to Encke's memoir; admits its conclusions, if the premises shall be found valid, and adds: "accordingly, (no other mode of accounting for the phenomenon appearing,) this is the solution proposed by Encke, and generally received." Mrs. Somerville, adverting, also, to Encke's memoir, deems the existence of resisting ether rendered "all but certain, within a few years, by the motion of comets;" and this insinuated negation she quite recalls some eight pages afterwards, by substituting the emphatick words, "which puts the existence of ether beyond a doubt." The same pen not only prophesies that by this resistance, comets will be finally precipitated upon the sun, but also that "the same cause may affect the motions of the planets, and be ultimately the means of destroying the solar system." Upon this memoir of Encke, theological arguments have been founded, having for their object to prove the destruction of the solar system, through the agency of this ether; and so certain has that result been considered, upon this authority, that the most positive forms of expression have been employed in pointing to such a consummation.

It is believed that we have assembled, above, the leading facts and arguments upon the *affirmative* of the position of a resisting medium to the planets, so far as to embrace all that is requisite and necessary for a clear understanding and subsequent impartial investigation of the question. The method of division incident to this arrangement has been adopted in the belief that such arrangement would afford a view, more distinct than any other, of the entire question. We proceed, then, to subject the several positions and arguments to examination, in the order of their occurrence.

The evidences, if any, upon which the Bramins and the Chaldeans founded their belief in the existence of this ether, not having come down to us, the reasons for their faith are placed beyond investigation: nor are we better circumstanced in relation to the opinions of Alhazen, Tycho Brahe, and some others who, while they supposed such ether to occupy the celestial regions, gave no demonstration of the fact, nor made application of it to any of the known purposes of the universe. The opinions of Kepler, upon this subject, may not have received less credence, in the day they were uttered, than did his discovery of the fundamental laws of the celestial movements; but they were promptly consigned to oblivion by the subsequent revelation that comets, no less than planets, belong to our solar system, and move in ellipses more or less elongated, about the sun, obeying the same laws as the grosser planets. Of Descartes' system, and of its fate, we have spoken. That system was undermined by the discovery and application of the law of universal gravitation; and as this ether constituted all that was most essential to the Cartesian doctrine, the celestial motions were no sooner found to be carried on independently of its aid, than the whole theory was abandoned. Newton, himself, as we have seen, applied this substance, under the name of "a most subtile spirit," to the production of certain results, in his Principles of Natural Philosophy, and again in his Opticks. The passages we have quoted. These positions appear to have had their origin in a desire so to explain the doctrine of gravitation as to free it from the implied assertion that bodies act in places where they are not—a form of attack which the metaphysicians chose to employ against it. Yet this was but subjecting the question to new difficulties; as there is nothing like a satisfactory explanation of gravity in the existence of this elastick ether. True, a fluid dis-

posed as Newton has assumed, would urge bodies in the direction he supposed; but what could maintain this fluid in the condition of its density varying according to the assumed law, is as inexplicable as the gravity it was meant to explain. The nature of such a fluid, if unrestrained, must be to equalise the density of all its parts, to the destruction of this hypothesis. That Newton did not consider gravity inherent in matter is manifest from the passages under consideration; and he most fully states this, in words, in one of his letters to Dr. Bently, as quoted by Prof. Playfair. Yet how he should have supposed he had escaped its necessity by his resort to the agency of this ether—since it is clearly for this purpose that he sought its aid—may well be deemed inexplicable. "If two particles of matter, at opposite extremities of the diameter of the earth, attract one another, this effect is just as little intelligible, and the *modus agendi* is just as mysterious, on the supposition that the whole globe of the earth is interposed, as on that of nothing, whatever, being interposed, or of a complete vacuum existing between them It is not enough that each particle attracts that in contact with it; it must attract the particles that are distant, and the intervention of particles between them does not render this at all more intelligible." We may close this point of investigation, by arraying Newton against himself. Notwithstanding the force with which Newton supposed bodies to be urged by the unequal density of the ether, in certain directions, yet, when treating of the tails of comets, his language is, "from whence, again, we have another argument proving the celestial spaces to be free and without resistance, since in them not only the solid bodies of the planets and comets, but also the extremely rare vapours of comets' tails maintain their rapid motions with great freedom, and for an exceeding

long time." To such and kindred anomalies have the greatest minds been occasionally subject, in all ages.

We have seen that, in 1762, this theory of resistance had so far commanded attention that the French Academy offered, in that year, a prize for the best examination of it; and we have also seen upon what evidences this prize was awarded. The results of the most careful modern observation, compared with those of a very ancient date, including some eclipses observed at Babylon, as early as 719, 720, and 721 years before the Christian era, show very clearly that the period of the moon's revolution is shorter in modern than in those remote ages. This acceleration, Dr. Halley, the English astronomer, in 1695, believed to exist, and declared his conviction that he could demonstrate the fact. A more detailed and extensive labour of comparison was subsequently performed by the *Rev. Richard Dunthorne*, who, in 1749, published its results, and verified the truth of the suspicions of his predecessor. It was the cause of this acceleration which the French Academy demanded, in 1762. M. l'abbé Bossut sought that cause in the resistance of ether; and believing he had discovered it there, he made such returns of his labours to the Academy, that the proffered prize was awarded him: nor was the errour into which he had fallen, discovered for almost a quarter of a century afterwards. In 1786, however, the true cause was revealed. In that year *M. le Marquis de Laplace* discovered both the cause and the law of this acceleration. He demonstrated that it is produced by the action of the sun upon the moon; that it varies with the eccentricity of the terrestrial orbit, and consequently that such acceleration is a necessary result of the law of universal gravitation. In a chapter founded upon the assumed possibility of a resisting ethereal fluid, Laplace says: "Hence it follows, that the resistance of the ether can become sensible, in the

moon's mean motion only. Ancient and modern observations evidently prove that the mean motions of the moon's perigee and nodes are subject to very sensible secular inequalities. The secular motion of the perigee, deduced from the comparison of ancient and modern observations, is less by eight or nine sexagesimal minutes, than that which results from the comparison of the observations made in the last century. This phenomenon, of which no doubt can remain, must, therefore, depend upon some other cause than the resistance of ether. We have seen that it depends on the variation of the eccentricity of the earth's orbit; and, as the secular equations resulting from that variation satisfy, completely, all the ancient and modern observations, we may conclude that the acceleration, produced by the resistance of an etherial fluid, on the moon's mean motion, is yet insensible." Again: "the accordance of theory with observation proves to us that if the mean movements of the moon are varied by causes foreign to the law of universal gravity, their influence is so small as not yet to have become sensible."

The errour or *Fracastor* and *Apian*, in regard to the uniform direction of the tails of comets, has enjoyed an extent of credence not often secured to a false position. Although a direction nearly in prolongation of the radius vector of the sun and the comet is not unusual for these tails, yet observations very early furnished exceptions enough to destroy the rule which has been so long adhered to in this particular. If, as Pingré supposed, the resistance of ether has any agency in producing these tails, we should always expect them to be situated *behind* the nucleus, relatively to the comet's actual motion, without relation to the position of the sun; but this is not so. Indeed they form so many different angles, both in regard to the comet's line of motion, and to the relative position

of the sun, that no settled fact seems deducible from the circumstance of their direction. Flamsted, in his account of a comet which he observed at Greenwich, in May, 1677, is at the pains to state that its tail was not directed in a line opposite the sun, but deviated therefrom at an angle of ten degrees. Hevelius, of a comet he observed, in 1682, says, "sometimes its tail was directed pretty exactly in opposition to the sun, as August 30, in the morning; but often with a considerable deviation, as is usual in most comets." The great comet of 1744 had, at one time, no less than *six* distinct tails, spread out like a fan. They were each about 4° broad; and the space between these several tails was as dark as the rest of the heavens. There exist other examples of the tails of comets which have separated into several branches. Newton cites two comets, the tails of which deviated from a right line joining the sun and comet, one ten, and the other no less than twenty-one degrees. The comet which appeared in January, 1824, besides the usual tail, opposite the sun, had another directed from the nucleus of the comet *towards* the sun. "The singular form of this comet," says the narrator, "adds new difficulties to the problem by which it has been explained, in a manner quite satisfactory, that the impulsion of the sun's rays is the principal cause of comets' tails always taking a direction opposite to the sun." Much that has been written upon the cause, nature and character of these peculiar appendages of comets, appears to have been based entirely upon assumed data. Such authority is alike unsafe and detrimental. The views of Arago are more sane, and therefore more valuable. "Kepler supposed the formation of the tails of comets was the result of the impulsion of the solar rays, which detached from the head of the comet the lighter portions of that body, and removed them to a distance beyond it. To render this expla-

nation admissible it is necessary to prove that the solar rays are endowed with an impulsive force; for the most delicate experiments have hitherto failed to enner such force perceptible. This force shown and admitted, it will still remain to be demonstrated why the tail is not always situated opposite to the sun; why there are sometimes several tails, making, one with another, so great angles; why they form and again vanish, in so short periods of time; why some of them have a rapid rotary motion; and finally, why some comets, of which the envelope seems very light and delicate, exhibit no trace of this appendage. A crowd of other theories, more or less ingenious, have been proposed; but they all equally fail to explain the phenomena."

The enormous length to which these tails have sometimes attained, has given rise to theories no less fanciful, nor yet more philosophical, respecting the consequences of such elongation. Newton supposed that the extremely distant portions of these tails could never be recalled, by attraction, to the nucleus of the comet, but must be scattered through the heavens, to be subsequently gathered to the different planets by attraction, and mingled with their atmospheres, to be there appropriated to supply the waste of matter spent upon vegetation, &c. Laplace, the younger Herschel, and some others among the moderns, have assumed, that portions of comets' tails are, at each revolution, "*scattered in space*," and that, consequently, these bodies are continually wasting away. So indefinite a phrase seems not well calculated to convey any idea of facts; for we must suppose the matter of these tails, however elongated from the nucleus of the comets, will still obey the laws of gravitation to those bodies, unless brought within the *stronger* attraction of some other body: and in either case no dissemination of matter would take place. But the diminution of

comet from loss of matter, by any cause, seems not well sustained. It is true that Arago, in 1832, fully concurred in this view; and hence advised us that in the then approaching return of Halley's comet we must not expect to behold so brilliant a body as the same had been at former periods of its return to the sun. But this opinion of that astronomer he did not find supported by the actual appearance of Halley's comet, in 1835; and this fact he has promptly announced. He has, also, collectively presented what has come down to us of the apparent size, length of tail, &c. of Halleys's comet at its various former apparitions; and contrasted this with the results of the careful and accurate observations upon the same body, made at various points, during its last appearance. At the close of these he adds: "If the reader will take the trouble to compare what I record of the comet of 1835 with the circumstances of its former apparitions, he certainly will not find in this collection of phenomena, *the proof* that Halley's comet is gradually diminishing. I will even say, that if, in a matter so delicate, observations made at very different periods of the year, will authorize any positive deduction, that which would most distinctly result from the two passages of 1759 and 1835, would be that the comet had increased in size during that interval. I ought to seize, with the more eagerness, this occasion to combat an errour extensively accredited, (a belief in the constant wasting away of comets,) because I believe I have somewhat contributed to its dissemination." This review of the theory of the diminution of comets, otherwise foreign to our subject, seemed demanded by the assumption of some that matter thus lost from these bodies will remain diffused through the celestial regions, of course offering constant obstruction to the progressive motion of the planets and comets. How such matter is to be maintained in this state of diffusion, has not, so far as

we know, been explained; nor is it easy for us to conceive how the body resisted or encountered by it shall be prevented from appropriating it to itself, by adding it to its own mass.*

Comets, from their great volumes, as compared with their masses, have justly been considered, of all celestial bodies, the most necessarily subject to the action of any resisting medium there may be in the regions in which they are moved. They are known to be subject to great disturbances, in their orbits, by the attraction of the planets of the solar system; and revolving as they do in ellipses of great eccentricity, many of these bodies having their aphelions at such immense distances as are not readily appreciable, by any of our methods of computation, their motions are much less subject to rigorous demonstration than those of the planets.† Still so much confidence had Prof. Encke

* The following "poetical license" occurs in the younger Herschel's Treatise on Astronomy, a late work, now used in some of the schools of this country. It contrasts very strangely with the really sane and valuable portions of that work, and it would hardly be supposed possible that it is from the same pen with these. The author is treating of Zodiacal light, upon which he thus fancifully expresses himself. "It is manifestly in the nature of a thin, lenticularly-formed atmosphere, surrounding the sun, and extending at least beyond the orbit of Mercury and even Venus, and may be conjectured to be no other than the denser parts of that medium, which, as we have reason to believe, resists the motion of comets; loaded, perhaps, with the actual materials of the tails of millions of those bodies, of which they have been stripped, in their successive perihelion passages, and which may be slowly subsiding into the sun"!

† Too many authors of just renown, have overlooked perspicuity, and written vaguely, upon this point. Brewster, (Encyclopedia,) has not wholly escaped the charge of sacrificing philosophical accuracy to euphony, in the following: "Traversing unseen the remote portion of its orbit, the comet wheels its ethereal course far beyond the limits of our system. What regions it there visits, or upon what destination it is sent, the limited powers of man are unable to discover. After the lapse of years, we perceive it again returning to our system, and tracing a portion of the same orbit

in the conclusions he had been able to draw, in the paper we have mentioned, that the movements of all these bodies which have been visible since its publication have been observed with increased care and assiduity; while the most rigid investigations of their former movements have not been overlooked.

According to Prof. Encke, the comet which bears his name, in its several revolutions, between 1786 and 1819, exhibited a mean decrease in the times of those revolutions. Now, as resistance, from an ethereal medium, would have the effect, by diminishing the velocity of the comet, to lessen its centrifugal force, and thus force it down nearer the sun, it follows that precisely the result which Encke observed, would be the effect of such resistance. To the agency of ether, therefore, was this diminution ascribed, though not until after all other circumstances which were supposed to have had any agency in the result had been carefully considered. Biela's comet, or the comet of six years and three quarters, was also observed with reference to this action of resisting ether; as was, finally, the comet of Halley, whose last disappearance was in 1836. These three are the only ones, of all that have been seen, whose regular, periodical return is known, at the present day. The acceleration in the mean motion of Encke's comet if not due to the resistance of ether, is still unexplaned. Biela's comet, in its return, in 1832, was also retarded, "but it throws new perplexity upon the question of a resisting medium. Encke and Gauss find a diminution of nine tenths of a day in the observed duration of its period,

round the sun, which it had formerly described." Now if it leave the sphere of our sun's attraction must it not of necessity, gravitate to some other body, and be thus prevented from ever returning? Laplace (Systeme du Monde,) has been more careful. He says, "innumerable comets, after having approached the sun, are elongated from it to such distances as to prove that its empire extends much beyond the known limits of our planetary system."

due to this resistance. Valz, from the computations of Damoiseau, finds this diminution to be eight tenths. Prof. Santini, from his own elements finds four tenths, while Encke's formula and constant, for computing this acceleration, only accounts for a diminution of three hundredths of a day. The mean of the three results would show that Biela's comet experiences the resistance of a medium twenty-five times as powerful as that which is encountered by Encke's comet." Halley's comet remains to be noticed. We have seen that the two above were accelerated, though very unequally, the cause of which was supposed to be the resisting ether. But Halley's comet, in its return to its perihelion, in 1835, was, from some cause, detained beyond its time for arriving at that point—a result directly opposite to that in the case of the other two bodies. "In traversing a resisting ether the comet of Halley would have arrived at its perihelion, in 1835, sooner than if moving in a void; now on the contrary, according to the calculations of M. Rosenberg, that body, by observation, was *six days* behind its time, according to the results of calculations disconnected from any allowance for the action of resisting ether. The difference, though much less, found by M. Pontécoulant, is of the same kind! Hitherto, then, the last appearance of Halley's comet has added nothing to our knowledge of the physical constitution of the celestial spaces."

We have said the acceleration of these bodies is unaccounted for: so is the retardation; but we shall presently see whether other agents than ether may, within the bounds of probability, be supposed to give rise to these. Clairaut, in announcing to the French Academy, in 1758, that the then expected return of Halley's comet would be retarded six hundred and eighteen days beyond its previous period, by the combined action of Jupiter and Saturn, adds that, "a body

which traverses regions so elongated from the sun, and which escapes, for so long periods, from our view, may be subject to forces totally unknown; such as the action of other comets, or even of planets, so distant from the sun as to have remained hitherto undiscovered." Uranus was unknown until 1781, twenty-three years after this announcement; and four other planets, belonging to our system, have been discovered within the present century—in all *five* since Clairaut penned his suggestion. The masses of the several planets, upon which so much depends in these investigations, appear more or less imperfectly known. Laplace gives the following table of them, that of the sun being taken for unity.

| | |
|---|---|
| Mercury, | $\frac{1}{2625810}$ |
| Venus, | $\frac{1}{405871}$ |
| The Earth, | $\frac{1}{354936}$ |
| Mars, | $\frac{1}{2546320}$ |
| Jupiter, | $\frac{1}{1070,3}$ |
| Saturn, | $\frac{1}{3512}$ |
| Uranus, | $\frac{1}{17918}$ |

Pentécoulant, from the same unit, gives the several masses of the same planets thus:

| | |
|---|---|
| Mercury, | $\frac{1}{1909706}$ |
| Venus, | $\frac{1}{401839}$ |
| The Earth, | $\frac{1}{356354}$ |
| Mars, | $\frac{1}{2680337}$ |
| Jupiter, | $\frac{1}{1053,924}$ |
| Saturn, | $\frac{1}{3512}$ |
| Uranus, | $\frac{1}{17918}$ |

These values, says our author, appear to us the most exact which have hitherto been obtained of the planetary masses. It will be observed that these two tables agree only in the masses of Saturn and Uranus; and of these Pontécoulant says it is very probable they need correcting, and that observations to determine that fact are in progress. This was in 1834.

Since that period this great geometrician has had cause to change his views in relation to some of these values. In calculating the perturbations of Halley's comet, he has made use of the following values, namely:

| | |
|---|---|
| Jupiter, . . . . | $\frac{1}{1048,69}$ |
| Saturn, . . . . | $\frac{1}{3500,2}$ |
| The Earth, . . . . | $\frac{1}{357500}$ |

These values, it will be seen, do not accord with those in either of the above tables. In the calculations here referred to, the action of Venus, Mercury and Mars was neglected as insensible. But a German geometrician, Rosenberg, on the contrary, has announced that the action of these three bodies, neglected as insensible by Pontécoulant, was sufficient to produce an acceleration of six days and one third in the return of Halley's comet. With all these uncertainties respecting the larger known planets of our system, we must not forget that the masses of the four new planets are in no degree known, beyond the fact that, compared with some of the older ones, they are very small. But still, small as they are, they are probably capable of exercising an influence, according to relative position, distance, &c. upon bodies as easily disturbed as comets; and yet no sane attempt at a demonstration of the amount of such influence can be made, in the present state of our knowledge, for want of the necessary data. Brewster, in endeavouring to account for the lost comet of 1770, supposed, what indeed the subsequent investigations of Laplace have rendered wholly improbable, namely, that one of these new planets had arrested that body in its course, and added it to its own mass. We have seen that the mass of Uranus, as well as of other planets, is unsettled: the number of its satellites is equally so. Herschel enumerates six. Laplace says powerful telescopes are necessary to perceive the second and

the fourth, and that the published observations of Herschel upon the other four are too few to determine the elements of their orbits, or even incontestably to assure us of their existence. The younger Herschel says of these satellites, "two undoubtedly exist, and four more have been suspected."

The immense periods of time consumed by some comets in performing their stated revolutions, are sufficient to convince us that the space beyond the orbit of the most distant planet now known to us, and within which moving bodies gravitate to our sun, is such that its extent could not easily be computed by any of our habitual methods. Whether planets still undiscovered by us are revolving there, in orbits beyond that of Uranus, is wholly unknown to us, and this ignorance of ours, while it continues, must involve in uncertainty the movements of all such comets as have their aphelions within the regions in question. The changes in the form and bulk of these bodies, in calculations so minute as have been attempted, to establish this theory of resistance, deserve attention. If, as appearances indicate, portions of the small masses of these bodies are occasionally removed from the nucleus or its vicinity to form the tails, which are sometimes extended to enormous lengths, while at others these portions of matter are reassembled around the nucleus, in whole or in part, these changes, by shifting the centre of gravity of the cometary body, must effect the action of foreign bodies thereon, and consequently influence the comet's motions. One other source of uncertainty, and one too which it would seem must forever remain such, in the movements of comets, is their action upon each other. To remove this source of errour no less would seem to be required than to identify every comet belonging to our solar system; to know the mass of each, the elements of the orbit it describes, as well as the elements of all those which perturbations may

cause it hereafter to assume; and to weigh all its disturbing forces with such accuracy as to be able to determine its place, relatively to the sun and to every other boby, at any given point of time. May not these numerous and active causes very well account, not only for the inequalities we have observed in the motions of comets, but even for much greater and more numerous ones, without the aid of a resisting medium? Some of these taken singly would, indeed, produce only slight results; but when it is considered that "in the immense ellipse described by a comet, the imperfection of analysis obliges the geometrician to follow that body step by step, as it were, without once losing sight of it for a single moment" throughout its revolutions, they may readily enough be supposed to cause greater deviations from calculated periods than "three one hundredths of a day, or less than forty-four minutes in a term of six years and three quarters. Pontécoulant deems it impossible, in the present state of science, to determine within one or two days, the instant of the passage of a comet through its perihelion; so very uncertain are the elements which astronomy furnishes for calculating their perturbations.

Having thus submitted the leading positions and arguments favourable to the theory of a resisting medium in the celestial regions, to detailed examination, the whole, according to the views we have taken, may be resolved into the following heads:

1st. That in periods of the most remote antiquity there prevailed a belief in the presence of ether in the celestial regions: but the proof, if any, upon which this belief was founded has not been preserved to us; nor are we better circumstanced, in reality, with regard to the basis of the faith of Alhazen, Tycho-Brahe, Kepler, &c., in regard to this subject: but this belief we must not forget, was not coupled, so far as we have seen, with the theory of resistance.

2d. That when the Cartesian theory arose, this ether, being an indispensable agent thereof, was every where believed in; not, indeed, as a resisting medium, but as a propelling one, which carried the planets forward in their orbits: this faith came to the ground with the doctrine of which it formed a part.

3d. When the laws of universal gravitation had exposed the errours of the Cartesian system, we find Newton still vaguely imagining of and concerning this substance, but in language so indistinct as not always to be definable; at one time supposing it to be the cause of gravity, and at other times, by its unequal density, mechanically giving direction to the motions of the heavenly bodies: the errour of these views is apparent.

4th. The ingenious arguments of Bossut, which took the prize of the French Academy, in 1762, were supposed to have well shown the resisting agency of this ether, in the acceleration of the moon's mean motion; and no doubts of the truth of this arose, until Laplace demonstrated that such acceleration is wholly due to the law of universal gravitation.

5th. That this ether has offered to the movements of comets a resistance which has rendered its agency appreciable. If the objections that have been offered against this are valid, they are much more than sufficient to destroy even its plausibility.

If the conclusions at which we have arrived, then, be correct, we have shown that the existence of this ethereal medium was for a long series of years believed in, without evidence known to us; that it has been, during another long series of years, even to the present day, accredited, also, upon different points of evidence, at different periods of time, but all which evidence has failed to sustain the fact of its existence; and that, therefore, to be hereafter adhered to, fresh evidences of its truth will be requisite to render it more

than a mere hypothesis, or gratuitous assumption: not that its existence has been disproved; but only that confirmatory evidence of that existence no longer remains.

The predictions, therefore, that have pointed at the destruction of the solar system, through the agency of a resisting ether, may very well be discarded. Inequalities there certainly are, in the motions of the heavenly bodies; but all these are confined within narrow limits, and they constantly oscillate around a mean position. This ensures the stability and duration of the system. Many of them, indeed, extend through vast periods of time, for their accomplishment; but they are all the necessary consequences of the ascertained laws of gravity, and can never exceed their known limits. They constitute, in the sublime language of Pontécoulant, "immense pendulums of eternity, which beat the ages as ours do the seconds!"

# DICTIONARY OF TERMS.

EXPLANATIONS OF SOME OF THE MORE COMMON ASTRONOMICAL TERMS.

*Aberration*, an apparent annual motion in the fixed stars, occasioned by the velocity of light, combined with the real velocity of the earth in its orbit.

*Aerolite*, a meteorick stone.

*Acromatick telescope*, see page 29.

*Altitude*, the height of the sun, moon, or stars above the horizon, reckoned upon a verticle circle, in degrees, minutes, &c.

*Angle*, the inclination or opening of two lines meeting in a point.

*Aphelion*, the point, in the orbit of a celestial body, where that body is at its greatest distance from the sun.

*Apogee*, see page 55.

*Apsides*, see page 55.

*Attraction*, a property of matter, by which bodies are made to approach each other, without any sensible agent to cause this.

*Axis*, an imaginary line through a planet, from pole to pole. Plural, *Axes*.

*Azimuth*, see page 54.

*Barometer*, an instrment by which changes in the weight of the atmosphere are measured.

*Circumpolar stars*, those stars which seem to revolve round either pole.

*Colures*, see page 54.

*Conjunction*, see page 54.

*Cycle*, a period of time, after which the same phenomena of the celestial bodies begin to occur again, in the same order.

*Cycle of the sun*, is a period of 28 years, which being completed, the days of the month return in the same order to the same days of the week; the sun's place to the same signs and degrees, in the ecliptick, &c.

*Cycle of the moon*, or Metonick cycle, called, also, the golden number, is a revolution of 19 years, which being completed, the new and full moons return to the same days of the month, &c.

*Declination*, see page 54.

*Direct.* A planet, or other celestial body, is said to have a direct motion, when it moves in the order of the signs, as from Aries towards Taurus, &c.

*Eccentricity*, see page 52.

*Ecliptick*, see page 54.

*Ellipse*, see page 49.

*Elongation*, the angular distance of a planet from the sun, as it appears to a spectator upon the earth.

*Emersion*, the time when any planet which is eclipsed begins to recover its light again.

*Equator*, see page 56.

*Equinoxes*, the two points where the ecliptick cuts the equator. When the sun is in either of these points the days and nights are equal—hence the name.

*Ellipticity*, eccentricity, or deviation from the circular or spherical form.

*Focus*, see page 25.

*Foci of an ellipse*, see page 52.

*Galaxy*, the Milky-Way, a bright zone among the stars.

*Gnomon*, an instrument, or apparatus for measuring the altitudes, declinations, &c. of the celestial bodies.

*Golden Numbers*, a series of numbers, from one to nineteen, which are used in almanacks, for determining the times of new and full moons.

*Hesperus*, a name given to Venus when she appears in the evening.

*Horizon*, see page 54.

*Hour circles*, the same with meridians, or great circles which pass through the poles of the world, and are perpendicular to the equator.

*Immersion*, the moment when an eclipse begins, or when a planet enters into the dark shadow.

*Inclination*, the angle which the orbit of one planet or comet makes with that of another, or with the ecliptick.

*Inferiour planets*, see page 48.

*Incidence of light*, the angle which rays make with a perpendicular to the surface upon which they fall. Page 19, fig. 1, A B is the reflecting surface, S I is the incident, and I O the reflected ray. The angles formed, by these two rays, with a perpendicular to A B will be found equal to each other.

*Latitude*, see page 54.

*Longitude*, see page 54.

*Libration of the moon*, see pages 110 and 111.

*Lucifer*. Venus is so called when she is morning star, and rises before the sun.

*Magnitudes*, the fixed stars are divided into eight sizes, or classes, and they are designated, according to their sizes, as of the first, second, &c. magnitude, the numbering commencing with the largest. All these numbers, from first to sixth, inclusive, are stars visible to the naked eye, but those of the 7th and 8th magnitudes are telescopick stars.

*Meridian*, see page 55.

*Micrometer*, an instrument having a system of cross wires or threads, moveable upon a graduated surface, and which, when attached to telescopes, is employed in measuring the diameters of celestial bodies. See page 75.

*Mean motion of a planet*, is that motion which would

take place if it moved in a perfectly circular orbit, round the sun, and had, therein, a perfectly uniform velocity.

*Meniscus*, see page 24, figs. 7 and 8.

*Nadir*, see page 55.

*Nebulæ*, clusters of small stars which the telescope discloses, in different parts of the sky, and which have been so named on account of their cloudy appearance..

*Nodes*, see page 55.

*Nucleus of a comet*, see page 190.

*Opposition*, see page 54.

*Orbit*, see page 49.

*Occultation*, is when a star or planet is hid from our sight by the interposition of the moon, or some other planet.

*Parabola*, see page 56.

*Parallax*, see page 56.

*Penumbra*, see page 224.

*Perigee*, see page 55.

*Phases*, the several appearances of the moon and planets, according as a greater or less part of their illuminated hemispheres is presented to our sight. For phases of the moon, see fig. 24, page 108.

*Planets*, (primary,) are those bodies belonging to our solar system which regard the sun as their centre of motion: they are eleven in number, namely, Mercury, Venus, Earth, Mars, Vesta, Juno, Ceres, Pallas, Jupiter, Saturn, Uranus.

*Planets*, (secondary,) are satellites, or moons, which revolve round some one of the primary planets, regarding this as their centre, as the primary planets do the sun. Of these there are revolving round the earth, one; Jupiter, four; Saturn, seven; Uranus, six: total, 18.

*Poles*, see page 55.

*Plane*, length and breadth, without thickness. The

space included within a ring is the plane of that ring; and so of the orbit of a planet, &c.

*Positions of the sphere*, see page 56.

*Quadrature*, a celestial body is said to be in quadrature when it is 90°, or ¼ of the entire circle from the sun.

*Refraction*, is that variation of direction which the rays of light suffer by passing through mediums of different densities. For illustration, see page 255.

*Reflection of light*, see page 17.

*Radius vector;* an imaginary right line from the centre of the sun to the centre of any planet, is called the radius vector of the sun and that planet. Although all the planets vary their distances from the sun, during their revolutions, and consequently move faster at some times than at others, yet Kepler discovered that this imaginary line always passes over equal areas in equal times.

*Retrograde*, a planet or comet is said to have a retrograde motion when it moves in a direction contrary to the order of the signs. See "direct."

*Sidereal*, of or belonging to the stars.

*Sidereal day*, the time included between two succeeding transits of the same star across the same meridian.

*Sidereal year*, the time included between two successive returns of the sun to the same star.

*Signs of the Zodiack*, see page 58.

*Solstices*, see page 55.

*Solsticial points*, are the two signs of the zodiack, namely, Cancer and Capricorn, at which the ecliptick touches the tropicks, and into which the sun enters on our longest and shortest days.

*System*, a number of bodies revolving round a common centre, as the planets and comets revolve round the sun.

*Syzygies*, those points of the moon's orbit in which that planet is at the time of her new and full.

*Telescopick stars*, those stars which are not visible to the naked eye, but are only to be seen through the aid of the telescope.

*Transit*, is the passing of one celestial body before another, so as to render any part of the most distant body invisible. It is also used to denote the passage of a celestial body across the meridian of a place.

*Tropicks*, see page 55.

*Trajectory*, is the curve described by a body in motion. The ellipses described by the planets and comets, round the sun, and the curved path followed by a ray of light, in the atmosphere, &c. are trajectories.

*Translation*, is used, in astronomy, to designate the progressive motion of a planet in its orbit, from one part or point to another.

*Vertical circles*, the same as Azimuth circles, or such as are drawn perpendicularly to the horizon.

*Vertical plane*, the surface included within the circumference of a vertical circle, (which see,) and consequently a plane following the plumb line, and at right angles to the horizon.

*Zenith*, see page 55.

*Zodiack*, see page 58.

*Zones.* This name is applied to the five great divisions of the globe, namely, the *torid zone*, which is comprised between the two tropicks; the two *temtemperate zones*, northern and southern, lying between the northern and southern tropicks and the two polar circles; and the two *frozen zones*, northern and southern, lying between the polar circles and the poles.

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